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COLLOFORM SULPHIDE VEINS OF PORT AU PORT PENINSULA, NEWFOUNDLAND.[1]

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ABSTRACT.

At the Goodyear Prospect on the Port au Port peninsula in southwestern Newfoundland, narrow, lenticular, crustified veins occupy prominent vertical joints which strike parallel to the axis of a broad anticline in Ordovician limestone. The abundant calcite gangue exhibits excellent comb structure. Galena, the most plentiful sulphide, occurs mainly as subparallel, elongate growths of cubes oriented with trigonal axes normal to the banding of the veins. Zinc sulphide occurs principally as finely colloform-banded, brown sphalerite with bladed structure normal to the banding. An immersion medium of high index revealed wurtzite. Marcasite commonly occurs as nodules displaying concentric banding and radial fibrous structure. Properties of an anomalous variety of marcasite are listed. Pyrite in small amounts is generally associated with marcasite. Fine black powder occurring in marcasite nodules was shown by X-ray to be mainly marcasite. The paragenesis of the primary minerals is given; pyrite and marcasite, and, sphalerite and wurtzite which occur in close spatial association in the ore are believed to be essentially contemporaneous.

Evidence is presented that the ores were deposited in post-upper Mississippian time under conditions of low temperature and pressure. Several textural features of the sulphides suggest the importance of colloidal phenomena. Although intrusives are unknown in the vicinity of the deposits, igneous rocks of post-upper Paleozoic age occur in a few places in Newfoundland.

[1] Princeton University Contribution to the Geology of Newfoundland, No. 22.

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INTRODUCTION.

SEVERAL deposits of colloform lead, zinc, and iron sulphides occur in Europe, but similar deposits appear to be very rare in North America. The following description of colloform sulphide veins of the Port au Port peninsula of Newfoundland therefore, should be of interest.

The Port au Port peninsula is situated in southwestern Newfoundland between latitudes 48° 28′ and 48° 48′ north and between longitudes 58° 40′ and 59° 16′ west (Fig. 1). Small lead deposits on the peninsula at Spider Pond, Lead Cove, and Tush Cove and iron sulphide deposits at Bellmans Cove have been prospected by shallow shafts or short adits at various times in

the past. Additional sulphide deposits occur at Piccadilly Harbor, Abrahams Cove and Man o' War Cove (Fig. 2).

A report by J. W. Sullivan [2] dealing mainly with the stratigraphy of the Port au Port peninsula includes a brief description of some of the mineral deposits of the region.

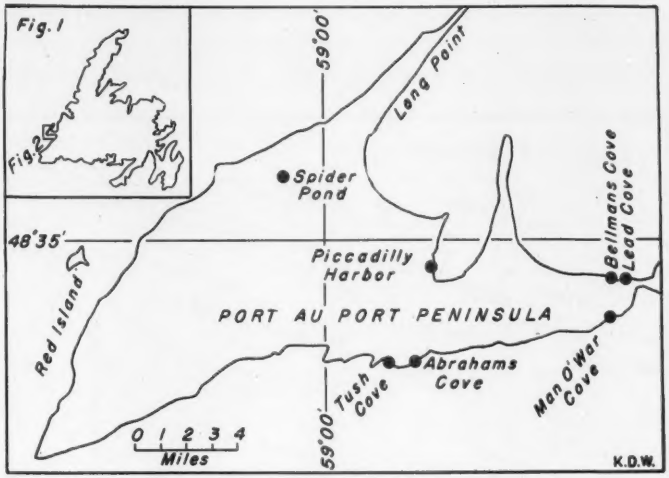

FIG. 1. Index map of Newfoundland showing position of Port au Port peninsula.

FIG. 2. Index map of Port au Port peninsula showing positions of deposits to which reference is made.

The iron sulphide deposits in the eastern part of the area were briefly discussed by C. A. Meissner [3] at an early date.

According to Sullivan,[4] the rocks exposed on the Port au Port peninsula are entirely sedimentary, except for one small outcrop of pillow lava. These sediments, about 14,000 feet thick, range

[2] Sullivan, J. W.: The geology and mineral resources of the Port au Port area, Newfoundland. Unpublished Ph.D. dissertation. Yale University, 1940.

[3] Meissner, C. A.: Some of the pyrites deposits at Port au Port, Newfoundland. Eng. and Min. Jour. 73: 626–627, 1902.

[4] Op. cit., p. 14.

from middle Cambrian to upper Mississippian in age, and consist of limestone and dolomite with a minor amount of sandstone and shale. The competent carbonate rocks of the southern part of the peninsula are thrown into broad open folds broken by great thrust faults.[5] Northward displacement of considerable magnitude along the thrusts has produced complex minor structures in the incompetent strata of the section. In the central part of the peninsula the rocks have been downthrown on the east of several northeastward-trending vertical faults. Narrow grabens bounded

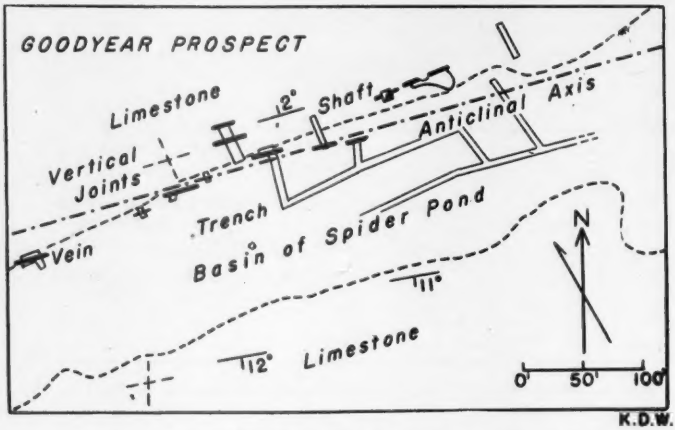

FIG. 3. Map of the Goodyear Prospect at Spider Pond.

by northward-striking vertical faults are numerous in the eastern part of the region (Fig. 21).

GOODYEAR PROSPECT (SPIDER POND).

The principal veins of the Goodyear prospect were discovered about fifteen years ago on the northern margin of a shallow lake known as Spider Pond (Fig. 2). Draining of the pond and subsequent trenching in the basin have revealed additional narrow veins.

[5] Sullivan, J. W.: op. cit., p. 77.

Geology. The rock exposed in the vicinity of the prospect is massive, thickly-bedded, fossiliferous, gray limestone of Ordovician age which has been folded into a broad gentle anticline trending about N 75° E (Fig. 3). Nonpersistent veins ranging from a few inches to a foot thick occur near the crest of the fold in prominent vertical joints which are parallel to the strike of the structure.

Veins. The lenticular character of the veins is very marked. One vein observed by the writer pinched from a width of 7 inches to 1½ inches within a vertical distance of 1½ feet and swelled again to 9 inches within an additional 2½ feet (Fig. 4).

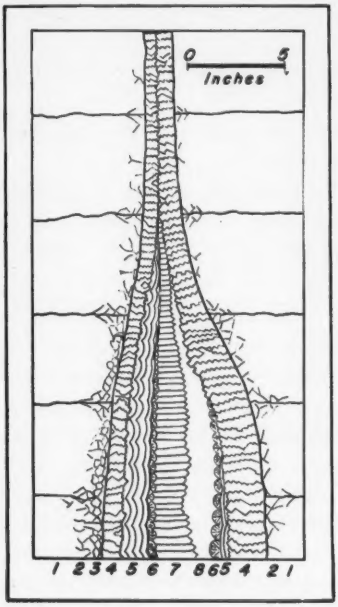

FIG. 4. Drawing of Vertical Section of vein exposed in trench situated 140 feet west of shaft at Goodyear prospect. 1. massive limestone, 2. limestone transected by calcite seams, 3. limestone breccia cemented by calcite, 4. galena, 5. mainly sphalerite, 6. mainly marcasite, 7. calcite, 8. vug.

Generally, the veins are flanked by narrow zones of finely brecciated limestone which has been recemented by coarsely crystalline white calcite. In a few places a thin film of gouge was observed separating slickensided vein surfaces from massive country rock. Although the limestone wall rock is traversed by minute seams of white calcite and contains occasional grains of iron sulphide, macroscopically, it appears to be normal in other respects. A microscopic study of brecciated wallrock revealed slight recrystallization of the margins of the fragments.

In general, the veins exhibit excellent crustification and drusy structure (Fig. 4). The complete sequence of bands, observable macroscopically, includes essentally the following, from wallrock to center:

1. Coarsely crystalline white calcite commonly displaying comb structure.
2. Coarsely crystalline galena with crystals greatly elongated normal to the walls.
3. Finely colloform-banded, brown sphalerite showing bladed structure normal to the banding.
4. Marcasite, commonly occurring as nodules with concentric banding and radial fibrous structure.
5. Coarsely crystalline white calcite commonly displaying comb structure.

In several cases, the first stage of calcite deposition was only of minor importance. Commonly, the sphalerite, marcasite, and inner calcite zones pinch out as the veins decrease in width.

Lack of symmetry in the banding is very noticeable. In a few places it was observed that a well-defined band was practically lacking in a counterpart on the opposite side of the vein.

Mineralogy. Calcite, galena, sphalerite, marcasite, cerussite, and limonite are apparent megascopically in the veins at Spider Pond. Laboratory study has revealed the presence of a considerable quantity of pyrite and a small amount of wurtzite and chalcopyrite.

Calcite occurs in the wallrock of the deposits as minute veinlets transecting massive limestone and as cementing material be-

tween fragments in the breccia. In the veins themselves, calcite most commonly constitutes the oldest and the youngest bands, but a small amount occurs as disseminated grains in the intervening sulphides. The calcite of the two principal bands is coarsely crystalline, white to pale gray in color, and generally exhibits excellent comb structure which consists of prisms terminating in scalenohedrons or acute rhombohedrons. A small quantity of extremely fine-grained, buff-colored calcite occurs in the veins at various places.

Galena, in the majority of cases, is the most abundant metallic mineral in the veins. It was generally preceded by a small amount of marcasite, pyrite, sphalerite, and chalcopyrite, but was the first sulphide to be deposited copiously. The principal band of galena in the veins is followed by the main zone of sphalerite; nevertheless, the deposition of galena in relatively small amounts persisted until late in the sequence.

The galena is coarsely crystalline and, in the main band, invariably displays subparallel, elongate growths of cubes oriented with body diagonals approximately normal to the banding (Figs. 4, 5). The crystals comprising the elongate growths commonly show lineage structure. The latest galena occurs in the vugs as small, well-formed crystals which are generally cubes (Fig. 11) but in some cases, octahedrons or combinations of the two forms.

Sphalerite occurs chiefly in a finely-banded zone which was deposited after most of the galena and before most of the marcasite (Fig. 4). A small amount was deposited early in the sequence in association with chalcopyrite and calcite, and a little persisted until the termination of sulphide deposition.

In many cases, the boundary between the galena and sphalerite bands is somewhat irregular due to the replacement of the galena along its cleavages (*e.g.* Figs. 6, 17). The sphalerite zone is made up principally of alternating scalloped bands of light buff, brown and black sphalerite, which contains a small amount of wurtzite (Figs. 6, 7, 8). Fifteen to thirty bands per centimeter are common. In a few cases, marcasite and calcite constitute occasional bands (Figs. 6, 8). Rhythmic banding in sphalerite

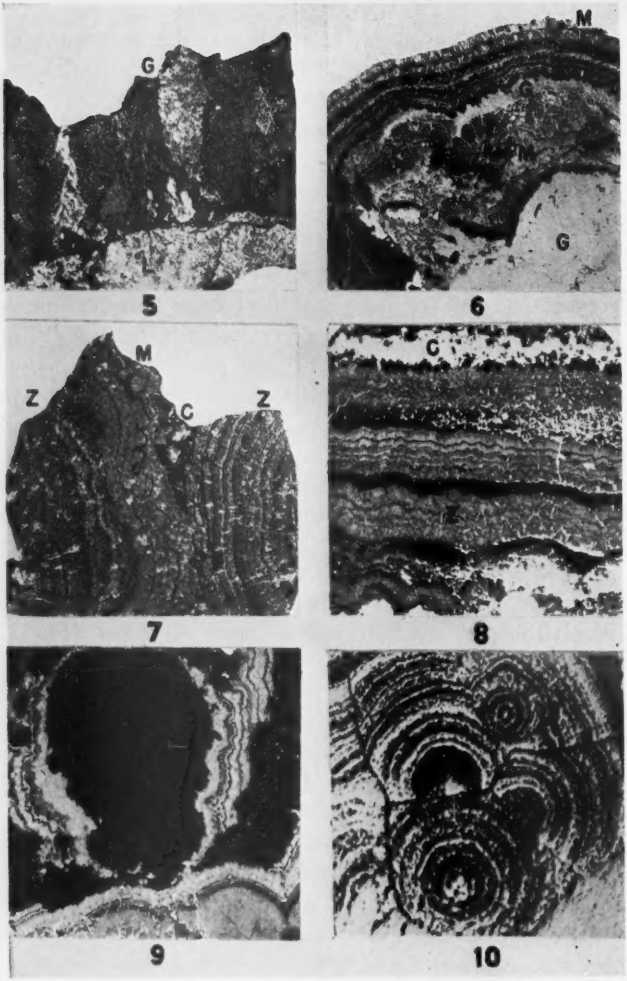

FIG. 5. Galena (G) showing subparallel elongate growths oriented approximately normal to wall of vein. L—limestone. Ground surface. Natural size.

deposited upon acutely terminated calcite crystals has resulted in a crenulated structure (Figs. 12, 14) which closely resembles the colloform scalloped banding referred to above. Nodular vug surfaces have commonly resulted from the modified inheritance of calcite terminations through this pseudo-colloform-scalloped sphalerite (Fig. 11).

The finely-banded sphalerite displays distinct, bladed crystals oriented approximately normal to the banding (Figs. 6, 7, 12). In many cases (*e.g.* Fig. 7) an individual crystal extends through several adjacent bands.

The late sphalerite occurs principally as small dark brown, complexly intergrown, twinned crystals lining vugs. Occasionally, however, botryoidal masses were formed which consist of concentrically banded spherules of radial fibrous, light yellow sphalerite containing small amounts of radially arranged galena (Figs. 10, 15).

Wurtzite. The similarity between the delicately scalloped bands and concentrically banded spherules of zinc sulphide described above, and the structures in the schalenblende of the European colloform zinc-lead ores suggested the possibility of the occurrence of wurtzite at Spider Pond. In polished sections, anisotropism would be difficult to detect in much of the zinc sulphide because of its high internal reflection, and in thin sections, the extremely high refractive index of zinc sulphide relative to

FIG. 6. Interbanded marcasite (M), sphalerite (dark gray) and galena (G). Note small hemispheres of marcasite, fibrous and bladed habit of marcasite and sphalerite (lower left) and slight replacement of galena by sphalerite. Polished surface. Natural size.

FIG. 7. Finely-banded sphalerite and wurtzite displaying elongated crystals oriented approximately normal to banding. Z—sphalerite and wurtzite, M—marcasite, C—calcite. Ground surface. Natural size.

FIG. 8. Finely-banded zinc sulphine (Z), marcasite (black) and calcite (C) in thin section. × 3.

FIG. 9. Finely-banded zinc sulphide (gray) partially replaced by marcasite (black). Note scalloped banding in lower right. Thin section. × 2.5.

FIG. 10. Photomicrograph of polished surface of sphalerite showing colloform texture. × 47.

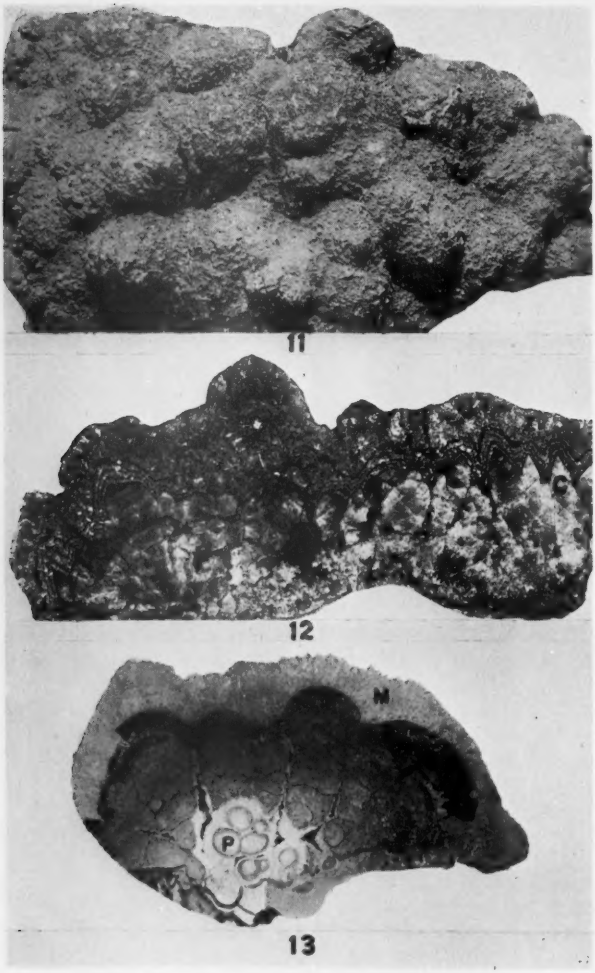

FIG. 11. Nodular vug surface resulting from deposition of sulphides upon terminations of calcite crystals. Note cubes of galena. Natural size.

that of balsam, prevents extinction with crossed nicols. However, examination of grains mounted in a medium of high index composed of amorphous sulphur and selenium[6] revealed a small amount of anisotropic zinc sulphide which was concluded to be wurtzite.

Long bladed crystals of sphalerite have been regarded as indicative of the original deposition of zinc sulphide as wurtzite which has subsequently inverted to the isometric form. Ehrenberg[7] has concluded that the common fibrous crystals of sphalerite in the Aachen lead-zinc deposits represent paramorphs after wurtzite. A similar conclusion has been reached regarding the origin of the bladed sphalerite in the Wisconsin lead-zinc deposits[8] to which the Spider Pond veins are mineralogically and texturally comparable in many respects. According to Behre:

> The elongated crystals of zinc sulphide are strongly suggestive of wurtzite but they are generally isotropic both under the reflecting microscope and by transmitted light. Only rarely do one or two relatively isolated individuals show birefringence and extinction. X-ray diffraction

[6] Merwin, H. E., and Larsen, E. S.: Mixtures of amorphous sulphur and selenium as immersion media for the determination of high refractive indices with the microscope. Am. Jour. Sci. 34: 42–47, 1912.

[7] Ehrenberg, H.: Der Aufbau der Schalenblenden der Aachener Bleizinkerzlagerstätten und der Einfluss ihres Eisengahaltes auf die Mineralbildung; zugleich ein Beitrag zur mikroskopischen Diagnose von Wurtzit und Zinkblende. Neues Jahrb., 64, Abt. A: 397–422, 1931.

[8] Behre, Chas. H., Jr., Scott, E. R., and Banfield, A. F.: The Wisconsin lead-zinc district. Prelim. Pap. Econ. Geol. 32: 783–809, 1937.

Behre, Chas. H., Jr.: Wisconsin-Illinois-Iowa lead-zinc district. Contributions to a Knowledge of the Lead and Zinc Deposits of the Mississippi Valley Region. G. S. A. Spec. Pap. No. 24: 114–118. 1939.

Fig. 12. Pseudo-colloform-scalloped banding resulting from rhythmic deposition of sphalerite and a minor amount of wurtzite on terminations of calcite crystals (C). Z—sphalerite and wurtzite. Dark gray—galena. Ground surface. Natural size.

Fig. 13. Nodule showing nuclear spherules of pyrite (P), peripheral zone of coarse-grained, radiating marcasite (M) and intermediate zone of softer, tarnishable, concentrically banded, radial fibrous marcasite. Note large radial syneresis cracks flanked by normal marcasite and also, smaller concentric cracks. Polished surface. ×2.7.

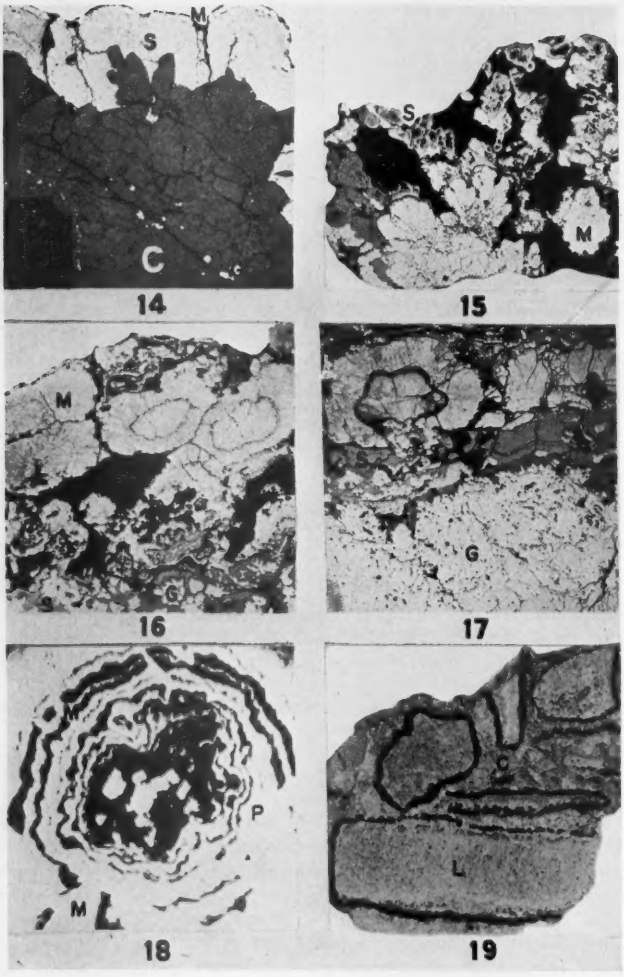

FIG. 14. Limestone fragment (lower left) containing minute grains of marcasite and pyrite (white) surrounded by calcite (C) containing disseminated marcasite and pyrite. G—galena, S—sphalerite, M—marcasite. Polished surface. Natural size.

patterns, kindly made for the author by Professor Paul F. Kerr of Columbia University, exhibit an isometric pattern; this is tentatively attributed by Professor Kerr, however, to inversion from wurtzite into sphalerite upon grinding.[9]

After deposition much of the iron sulphide and virtually all of the zinc sulphide changed slowly from their more unstable (marcasite, wurtzite) to their more stable (pyrite, sphalerite) forms.[10]

Van der Veen [11] has cited the occurrence of "elongated, often radially arranged crystal-grains, sometimes with an irregular twinning which produces iceflower-like textures" as a criterion for distinguishing wurtzite from sphalerite.

In contrast to the views of others, the writer suggests the possibility that the sphalerite and wurtzite of the Spider Pond deposits may have been formed contemporaneously. The experimental work of Allen and Crenshaw [12] on zinc sulphides has shown the

[9] Behre, Chas. H., Jr., Scott, E. R., and Banfield, A. F.: op. cit., p. 804.

[10] Behre, Chas. H., Jr., Scott, E. R., and Banfield, A. F.: op. cit., p. 809.

[11] Van der Veen, R. W.: Mineragraphy and Ore-Deposition. G. Naeff, The Hague, 1925. P. 38.

[12] Allen, E. T., and Crenshaw, J. L.: The sulphides of zinc, cadmium, and mercury; their crystalline forms and genetic conditions; microscopic study by H. E. Merwin. Am. Jour. Sci. 4th Ser. 34: 341–396, 1912.

——: Effect of temperature and acidity in the formation of marcasite (FeS_2) and wurtzite (ZnS); a contribution to the genesis of unstable forms. Microscopic Study by H. E. Merwin. Am. Jour. Sci. 4th Ser. 38: 393–431, 1914.

FIG. 15. Arborescent marcasite (M) containing some pyrite, and botryoidal masses of sphalerite (S) consisting of concentrically banded spherules. Polished surface. Natural size.

FIG. 16. Nodules of marcasite (M) containing zone of galena and pyrite. Note radial structure of outer marcasite zone. S—sphalerite, G—galena. Polished surface. Natural size.

FIG. 17. Nodule of marcasite consisting of marginal zone of normal mineral and large core of softer, tarnishable variety. Note radial crystallization, and radial cracks in inner zone. Note replacement of galena (G) by sphalerite (S). Polished surface. Natural size.

FIG. 18. Photomicrograph showing concentrically banded spherule of pyrite. Note few radially elongated crystals of marcasite. Specimen etched with HNO_3. × 108.

FIG. 19. Cockade ore consisting of fragments of limestone (L) rimmed with marcasite and sphalerite and cemented with calcite (C). Abrahams Cove. Polished surface. Natural size.

existence of "conditions of temperature and acidity under which the two minerals may be formed at will together and apparently simultaneously." [13]

The writer believes that the long bladed habit of the isometric zinc sulphide in the Spider Pond deposits does not necessarily imply original crystallization in the hexagonal system. Indeed, in the same deposits, the isometric mineral, galena, displays similar elongate growths oriented normal to the banding and elsewhere, other isometric minerals occur in fibrous or columnar forms.[14] Also, Allen, Crenshaw, and Merwin observed elongate groups of experimentally precipitated sphalerite crystals which "usually appeared at first sight to be single, deeply cross-striated, hexagonal prisms up to 0.2 mm. long, but further study indicated that they were strings of dodecahedra twinned after the spinel law." [15]

Chalcopyrite, observed in only a small proportion of the polished sections examined, occurs in close association with the early, dark brown to black sphalerite. It is present as anhedral grains with sphalerite and as subhedral crystals of sphenoidal habit disseminated in calcite. The chalcopyrite and sphalerite appear to have been deposited contemporaneously.

Marcasite was deposited early in the sequence as a sparse dissemination in limestone immediately adjacent to the veins and as occasional small crystals or groups of crystals near the outer edge of the early calcite band. Microscopic grains of pyrite are commonly intergrown with the marcasite. Marcasite also occurs in small amounts as disseminated crystals in the galena and as scattered grains and thin bands in the sphalerite but the majority of it was deposited after the sphalerite and before the late calcite. Commonly, this main marcasite zone exhibits well-defined banding with fibrous structure normal to the bands. Concentrically banded nodules showing radial fibrous structure occur in abundance; arborescent masses are less common. In most cases, mar-

[13] Ibid., p. 430.

[14] *E.g.* Cuprite (chalcotrichite)—capillary and acicular crystals at Copper Queen mine, Bisbee, and Detroit mine, Morenci.

Fluorite—fibrous habit at Baxter Mine, Fallon, Nevada; columnar habit at St. Lawrence, Newfoundland.

[15] Ibid., p. 413, 1914.

casite deposition was concluded with the growth of a crust of excellent, small, singly-terminated crystals which are elongated parallel to the b-axis and are bounded by distinctly curved prisms, and slightly curved, striated bases. In a few cases, the crystals were modified by the addition of the brachypinacoid.

The nodular masses mentioned above generally consist of iron sulphides alone but in a few cases (*e.g.* Fig. 16) other sulphides occur in small amounts. Pyrite, distinctly subordinate to marcasite in quantity, occurs as spherules near the nuclei of some nodules (Fig. 13) and in definite concentric bands grading into marcasite in others (Figs. 16, 18). The marcasite which occurs along the margins of radially disposed cracks (Fig. 13) in the nodules and which constitutes the broad peripheral zone (Figs. 13, 17) exhibits normal properties but that which occupies the nuclear and intermediate positions is distinctly anomalous. The contrast in properties of the two varieties is given in the following table:

TABLE I.

Properties.	Normal Marcasite.	Anomalous Marcasite.
Color	Very pale brass yellow	Brass yellow
Anisotropism	Strong. Colors: vivid yellow, pale green, steel blue, orange brown.	Moderate to weak. Colors: Bronze yellow, gray.
Hardness	6(F)	3.5–4(D)
Twinning	Lamellar and flame-like intergrowths common.	None apparent. Crystal boundaries indistinct.
Etch reactions	HNO_3: Etches brown with slow effervescence; fumes tarnish slightly. Other reagents: negative.	HNO_3: Etches dark brown with effervescence; fumes tarnish. Other reagents: negative.
Tarnish in air	None	Rapidly becomes light brown to black. Most distinct in outer part of zone.
Specific gravity of aggregate	4.84	4.63[1]
Porosity of aggregate	0.12%	0.69%[2]

[1] Average of 4 determinations. Minimum = 4.46.
[2] Average of 4 determinations. Maximum = 1.04%.

Small samples of normal marcasite and of the soft tarnishable variety were carefully drilled from a polished section of the nodule shown in Figure 13. These were submitted to Professor Ralph J. Holmes of Columbia University, who very kindly undertook an X-ray study and reported the following: "Both materials gave identical patterns and comparison with our standard patterns indicates that the material is marcasite." [16]

It is believed that the anomalous properties are attributable in part to the finely crystalline, porous character of the mineral.

Thin films of extremely fine grained black powder occur between the peripheral band of normal marcasite and the inner zone of the soft tarnishable variety and also between concentric zones of the latter itself. Professor Holmes also investigated a small amount of this material by means of X-rays and arrived at the following conclusion: "The X-ray pattern agrees with standard patterns of marcasite. There are a few additional weak lines which are not those of pyrite or sphalerite. These extra lines were too few and weak to permit identification." [17]

Pyrite was observed microscopically as minute grains associated with the early disseminated marcasite and as clusters of anhedral crystals, generally confined to fairly definite bands, in the principal marcasite zone. The interesting occurrence in the nodular masses of iron sulphide of nuclear spherules of pyrite (Fig. 13) and delicately scalloped rhythmic bands (Fig. 18) starting abruptly and grading outward into a concentric zone of radial fibrous marcasite has been mentioned. The pyrite and marcasite which occur in close spatial association in the ore appear to be essentially contemporaneous.

In polished sections, pyrite is distinctly yellowish in comparison to marcasite. The major portion of the pyrite examined displays moderately strong anisotropism (blue-gray, orange-brown) which, however, is very faint in contrast to that of the marcasite. During a recent investigation of variations in the properties of pyrite, Smith [18] found that about one half of the specimens studied

[16] Personal communication, July 6, 1942.

[17] Personal communication, January 23, 1943.

[18] Smith, F. G.: Variation in the properties of pyrite. Am. Min. 27: 1–19, 1942.

showed anisotropism. This he attributed to the fact that an excess of iron atoms in the molecule is inserted in a regular manner rather than at random.

Occurrence of Cryptocrystalline and Amorphous Iron Sulphide. Tarr[19] has described the occurrence of "black powder-like material" between alternating layers of radiatory fibrous marcasite and pyrite in a deposit near Fredricktown, Missouri.

> This is a sulphide, and probably was originally melnikovite, the amorphous black iron disulphide. The black mineral occurs between successive layers of pyrite about as frequently as between the pyrite and marcasite. It occurs very rarely between two layers of marcasite. . . .
>
> The black powder has tentatively been called melnikovite. It would be more correct to say it probably represents an original deposit of melnikovite, because the material, although a soft black powder, is not now magnetic. A careful study with a microscope revealed the presence of minute grains of pyrite all through the black powder which in all probability is now extremely finely divided pyrite, as the amorphous melnikovite passes over into crystalline pyrite in time.[20]

Melnikovite is the name applied by Doss to minute black grains of very soft (H = 2—3), relatively light (S.G. = 4.16—4.3), magnetic iron disulphide obtained from drill holes penetrating Miocene clays in Samara, Russia.[21] The material described was more readily decomposed by certain chemical reagents than the well known iron disulphides. Doss apparently considered the mineral to be an unstable amorphous iron disulphide and cited the fact that it absorbed certain dyes as evidence of its colloidal or gel character. He later described the alteration of labile melnikovite to stable pyrite and discussed the bearing of the change on the genesis of pyrite deposits.[22]

[19] Tarr, W. A.: Alternating deposition of pyrite, marcasite and possibly melnikovite. Am. Min. 12: 417–421, 1927.

[20] Tarr, W. A.: op. cit., p. 418.

[21] Doss, B.: Über das dritte Gasbohrloch auf dem Gute der Gebrüder Melnikow im Gouvernement Samara nebst ergänzenden Untersuchungen über das zweite Bohrloch ebendaselbst. Ann. géol. et min. d.l. Russie, 13: 129–146, 1911.

——: Über die Natur und Zusammensetzung des in miocänen Tonen des Gouvernements Samara auftretenden Schwefeleisens, Neues Jahrb. Min., etc. 33: 662–713, 1912.

[22] Doss, B.: Melnikowit, ein neues Eisenbisulfid, und seine Bedeutung für die Genesis der Kieslagerstätten. Zeits. prakt. Geol. 20: 453–483, 1912.

Subsequently, Niggli [23] adopted the name melnikovite for colloidal "$FeS_2 . n\ H_2O$" which changes to dense marcasite, and applied a term "Melnikowitgel" to a "Gelmineral" of composition "$FeS . n\ H_2O$, in certain cases bisulphide or oxysulphide," of which melnikovite is the "metacolloid" and pyrite or pyrrhotite the crystalline end product.[24]

Ehrenberg [25] has reported that the pyrite of the lead-zinc deposits of Aachen, Wiesloch, etc. occurs in three habits: gel form, elongated rays, and coarsely crystalline aggregates. Although the submicroscopic material is referred to as the gel form of FeS_2, or melnikovite, X-ray photographs revealed the pyrite lattice.

Schneiderhöhn and Ramdohr [26] use the term "Melnikovit-Pyrit" or "Melnikowitpyrit" for colloform material consisting mainly of pyrite which has resulted from the complete or almost complete crystallization of gels of "FeS and $FeS_2 \pm$ As."

Portmann [27] has described the alteration of pyrrhotite, in the deposits near Ohorn in Saxony, to a rhythmically banded sulphide with the following properties: high reflection (less than pyrrhotite or pyrite), brownish yellow color, isotropic or finely crystalline, and variable hardness. The mineral is considered to be pyrite with adsorbed FeS or in part, melnikovite, still as a gel.

Laudermilk and Woodford [28] have described iron sulphides which occur in silicate-bearing, crystalline limestones at Cascade Canyon and Riverside in southern California. Samples from the former locality containing pyrite and a readily soluble, finely disseminated, black iron sulphide were treated chemically. "From

[23] Niggli, P.: Lehrbuch der Mineralogie, II Spezielle Mineralogie. 1926. P. 490.

[24] Idem, p. 678.

[25] Ehrenberg, H.: Das Auftreten und die Eigenschaften ehemaliges FeS_2—Gele insbesonder auf metasomatischen Blei-Zinkerzlagerstätten. Neues Jahrb. Mineral. Geol. A. 57: 1303–1320, 1928.

——: Über eine Abart des Pyrits in metasomatischen Blei-Zinkerzlagerstätten. Z. Krist. 66: 478–480, 1928.

[26] Schneiderhöhn, H., and Ramdohr, P.: "Melnikovit-Pyrit" Kristallin gewordenes FeS_2—Gel. Lehrbuch der Erzmicroskopie 2: 170–173, 1931.

[27] Portmann, Waldemar: Über eine Erzlagerstätte am Hirschberge bei Ohorn im Kontakthofe des Lausitzer Granitmassives. Chemie der Erde, 9, (1): 55–65, 1934.

[28] Laudermilk, J. D., and Woodford, A. O.: Hydrous iron sulphide in California crystalline limestone. Am. Min. 25: 418–424, 1940.

the iron and sulphur percentages in the oxalic acid extract, and the sulphur extracted by aqua regia, it was calculated that the rock contains about 2 per cent FeS_2, pyrite, and 1 per cent FeS, probably as hydrotroilite." [29] At Riverside, the limestone contains dark streaks and patches which in most cases are pyrrhotite and "probably hydrotroilite. The sulphide grains commonly have cores of bronze-yellow pyrrhotite, . . . ; other grains are entirely black and very soft. Part of the black material appears to be magnetic; it may be melnikovite;" [30] Tests indicate an H_2O content of about 3 per cent (above 110°) in the black sulphide.[31]

Cryptocrystalline pyrite from the Leviathan sulphur mine in Alpine County, California, has been described in detail by Pabst.[32] The deposit consists of an impregnation by sulphur of completely opalized, fine grained andesite tuff. The pyrite occurs at the margins of the orebody as a replacement of the tuff and to a lesser extent as disseminated grains in sulphur well within the main body.

> The pyrite is all cryptocrystalline and mostly black or gray, only the most compact specimens showing a brownish color. The luster is earthy or dull, in a few cases submetallic. Some of the material is quite friable, but in part it reaches the normal hardness of pyrite.[33]

X-ray powder patterns of the hardest, most compact pyrite and the soft black, friable variety were found to be identical, except that the lines of the latter were slightly stronger.

From this review of the literature, it is seen that iron sulphides of varied occurrence and physical properties have been concluded to be in an amorphous or gel condition, upon little or no evidence. However, as Pabst has found, in the rare cases in which X-ray studies have been made, the material in question has been shown to be crystalline. The result of the X-ray investigation of the fine black powder in the iron sulphide nodules of the Goodyear

[29] Idem, p. 420.
[30] Idem, p. 420.
[31] Idem, p. 423.
[32] Pabst, A.: Cryptocrystalline pyrite from Alpine County, California. Am. Min. 25: 425–431, 1940.
[33] Idem, p. 427.

Prospect is in accordance with this, except that the material is mainly marcasite rather than pyrite.

Paragenesis. Field study of the veins and laboratory examination of representative polished surfaces and thin sections establish the paragenesis shown diagrammatically in Figure 20. Cerussite and limonite formed by the weathering of galena and iron sulphide respectively are not included in the table. Deposition of the vein minerals was generally preceded by brecciation and slight recrystallization of the limestone wallrock.

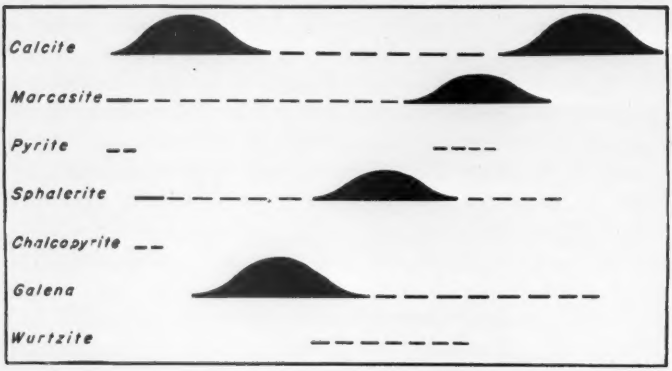

FIG. 20. Diagram showing paragenesis of primary minerals in Spider Pond deposits.

It is noteworthy that although the order of deposition of galena and sphalerite is in accordance with their solubilities in aqueous solutions,[34] it is the converse of the commonly observed paragenesis for which different explanations have recently been proposed by Ridge,[35] Smith,[36] and Garrels.[37] Apparently, however, there

[34] Verhoogen, Jean: Thermodynamical calculations of the solubility of some important sulphides, up to 400° C. ECON. GEOL. 33: 34–51, 1938.

[35] Ridge, John: Genesis of the Tri-State zinc and lead ores. ECON. GEOL. 31: 298–313, 1936.

[36] Smith, F. G.: Solution and precipitation of lead and zinc sulphides in sodium sulphide solutions. ECON. GEOL. 35: 646–658, 1940.

[37] Garrels, R. M.: The Mississippi Valley type lead-zinc deposits and the problem of mineral zoning. ECON. GEOL. 36: 729–744.

is evidence of deposition of considerable "wurtzitic blende" after galena in the colloform lead-zinc deposits of Europe.[38]

Small veins exposed near a pond to the north and in the brook to the east of the Goodyear Prospect display the same general sequence.

ADDITIONAL OCCURRENCES ON PENINSULA.

Piccadilly Harbor. Approximately one mile south of the wharf at Piccadilly (Fig. 2), gently-northward-dipping Ordovician limestone which strikes slightly north of east, is traversed diagonally by several narrow vertical veinlets which strike northwesterly. Generally, the veinlets are banded and vuggy and consist of white calcite containing minor amounts of galena, sphalerite, marcasite and pyrite. Some of the sphalerite occurs in vugs as relatively large, dark brown crystals with marcasite and calcite. The paragenesis is essentially similar to that of the Spider Pond deposits.

Tush Cove Prospect. At Tush Cove (Fig. 2), steeply-dipping calcite veins striking N 85° E transect Ordovician limestone which strikes N 65° E and dips northward at 10°. Generally, the marginal zones of the veins consist of finely-banded, brown, gray, and white, fibrous calcite. Thin plates of barite occur on calcite crystals of obtuse rhombohedral habit in vugs. Marcasite and galena are present in small amounts.

Abrahams Cove. On the western side of Abrahams Cove (Fig. 2), northwesterly-striking, vertical calcite veins occur in Ordovician limestone which strikes slightly north of east and dips gently northward. Finely-banded marginal zones of fibrous calcite are common. Calcite scalenohedrons up to 2 inches in length and galena crystals consisting of combinations of cube and octahedron, up to ¾ inches in diameter, are present in the vugs. The calcite crystals observed in one narrow vein displayed clearly-defined growth zones in various shades of gray, but an examination of the inequalities in growth and the distribution of the

[38] Behre, C. H.: European colloform ores of Mississippi Valley type. Amer. Min. 23: Abstract 2, 1938.

sulphide overgrowth [39] gave no conclusive evidence regarding the flow of the solutions. One vein was observed to terminate in an interesting breccia zone consisting of limestone fragments rimmed with marcasite and sphalerite and cemented by calcite (Fig. 19).

Lead Cove Prospect. At Lead Cove (Fig. 2), highly fossiliferous, cream-colored limestone of upper Mississippian [40] age occurs in a narrow northward-trending graben in thickly-bedded Ordovician limestone (Fig. 21). The Mississippian strata observed at the head of the cove are synclinal in structure and are highly brecciated for a considerable distance adjacent to the

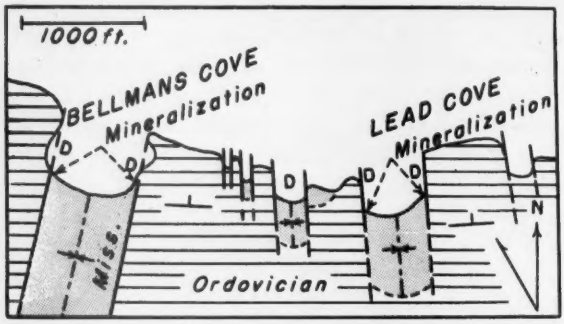

FIG. 21. Geologic map of Lead Cove and Bellmans Cove (Geology after Sullivan).

vertical faults which bound the graben. Marcasite and calcite are found in the limestone breccia on both the eastern and western sides of the cove. At the latter locality, the marcasite occurs interstitially as radiating sheafs of elongated, twinned crystals in association with a little pyrite. Irregular veinlets consisting essentially of marginal bands of galena with intervening calcite, transect the breccia of limestone and interstitial iron sulphide.

Bellmans Cove Prospect. At Bellmans Cove (Fig. 2), min-

[39] Newhouse, W. H.: The direction of flow of mineralizing solutions. ECON. GEOL. 36: 612–629, 1941.

[40] Sullivan, J. W.: op. cit., p. 85.

eralized breccia of cream-colored Mississippian [41] limestone occurs adjacent to northward-trending vertical faults which bound a large graben similar to the Lead Cove structure (Fig. 21). On the western side of the cove, large amounts of pyrite and calcite occur between the fragments. Pyrite is commonly present as large crystals displaying cubic and octahedral faces. Small crystals of marcasite enclosed within large pyrite grains were observed microscopically.

On the opposite side, the breccia contains marcasite, calcite, sphalerite, and barite. The barite is found as lamellar crystals which were deposited late in the sequence.

ORIGIN OF DEPOSITS.

Age of Mineralization. The mineral deposits in the brecciated upper Mississippian limestones at Lead Cove and Bellmans Cove are definitely post-upper Mississippian in age. Because of mineralogical and textural similarities, it is probable that the other sulphide deposits on the Port au Port peninsula are genetically related to these and are also of post-upper Mississippian age. Sullivan believes that the brecciation of the Mississippian limestones took place during the Appalachian Revolution.[42] Since mineralization occurred after the brecciation, it may represent a later phase of the orogeny. It is interesting to note that no mention of mineralization is contained in the reports dealing with the Carboniferous rocks occurring elsewhere in Newfoundland. The Port au Port occurrences therefore appear to be the youngest known sulphide deposits on the island.

Certain of the deposits on the peninsula are apparently similar in their broader structural features to small lead-zinc deposits in the southwestern continuation of the Appalachians, near Gaspe Bay, Quebec,[43] where the veins occupy steeply dipping breccia

[41] Sullivan, J. W.: op. cit., p. 89.

[42] Op. cit., p. 124.

[43] Jones, I. W.: Lead and zinc deposits near Gaspe Bay and on Marsoui River. Que. Bur. of Mines Ann. Rept., 1932, Part D, pp. 33–51.

——: Mineral deposits in Gaspe Peninsula, Quebec, in Ore Deposits as Related to Structural Features. Princeton Univ. Press, 1942. Pp. 184–187.

zones of little or no displacement, that transect folded limestone of lower Devonian age. Middle Devonian rocks which represent the youngest sediments in the region have been intruded by a few diabase dikes.

Temperature and Pressure. The lead-zinc deposits of the Port au Port peninsula clearly display crustified banding, vugs, and cockade ore, commonly regarded as characteristic of deposits formed at low temperature and pressure. The absence of significant wallrock alteration is also indicative of deposition under such conditions. The excellent lineage structure generally observable in the galena,[44] the scalenohedral and rhombohedral habit of the calcite[45] and the anisotropism commonly apparent in the pyrite are also suggestive of low temperature. Smith's investigations indicate that anisotropic pyrite forms below "some critical temperature, which is believed to be between room temperature and 135° C."[46]

Character of Solutions. During the formation of zinc and iron sulphides in the Spider Pond deposits, colloidal phenomena are believed to have been operative, because of common occurrence of the following features:[47] scalloped banding; concentrically banded spherules; banding within a single mineral; and, concentric cracks, radial cracks, and cuspate pores, suggestive of contraction upon syneresis. These colloform textures may have resulted from (1) the transportation of the constituents in true solution and their precipitation as colloids at the site of deposition or (2) the transportation of the constituents in a colloidal sol and their flocculation at the site of deposition. The absence of colloform textures in many parts of the Spider Pond ores and in the other deposits of the peninsula is indicative of precipitation from true

[44] Buerger, M. J.: The significance of "block structure" in crystals. Am. Min. 17: 177–191, 1932.

Smith, F. G.: Lineage structure and conditions of deposition of pyrite. Econ. Geol. 37: 519–523, 1942, p. 522.

[45] Schaller, W. T.: The crystal cavities of the New Jersey zeolite region. U. S. Geol. Surv. Bull. 832: 47, 1932.

[46] Smith, F. G.: op. cit., p. 13.

[47] Cf. Lasky, S. G.: A colloidal origin of some of the Kennecott ore minerals. Econ. Geol. 25: 737–758, 1930.

solutions. However, the experimental work of Kania [48] in which crystals of chalcopyrite and marcasite were obtained directly from sols, suggests the possibility of deposition from colloidal suspension.

In considering deposition from true solutions, the investigations of Allen and Crenshaw et al.[49] on iron and zinc sulphides, are of interest, but conclusions regarding the character of the solutions, based upon their results, are partially dependent upon the interpretation of the pyrite-marcasite and sphalerite-wurtzite relations in the ore. The writer believes that there is evidence of some contemporaneous deposition of pyrite and marcasite and has seen no evidence against a comparable relationship between sphalerite and wurtzite. This relationship indicates deposition from solutions of relatively low temperature and slight acidity. The stability of the limestone wallrock and of the calcite gangue also shows that highly acidic solutions could not have been present.[50] The possibility of deposition of colloidal zinc and iron sulphides from true solution is suggested by the abundance of "spherical aggregations" of amorphous precipitates and "globules," "stratified crusts" and "spherulites" of "stiff jelly" obtained by Allen and Crenshaw in the laboratory.

In considering precipitation from colloidal suspension as an alternative, the experiments of Smith[51] on lead and zinc sulphides are of significance. He found that sphalerite which crystallized upon the cooling of aqueous solutions of zinc sulphide in sodium polysulphide or NaHS was apparently dispersed by the solutions at lower temperature and coagulated at still lower temperature as

[48] Kania, J. E. A.: Some notes on the origin of pyritic copper deposits of the mesothermal type. ECON. GEOL. 31: 453–471, 1936.

[49] Allen, E. T., Crenshaw, J. L., and Johnston, John: The mineral sulphides of iron. With crystallographic study by Esper S. Larsen. Amer. Jour. Sci. 4th ser. 33: 169–236, 1912.

Allen, E. T., and Crenshaw, J. L.: op. cit., 1912.

——: op. cit., 1914.

[50] Cf. Graton, L. C.: Nature of the ore-forming fluid. ECON. GEOL. 35: 197–358, 1940, pp. 297–299.

[51] Smith, F. G.: Solution and precipitation of lead and zinc sulphides in sodium sulphide solutions. ECON. GEOL. 35: 646–658, 1940.

small crystals of sphalerite, colloform amorphous zinc sulphide, or wurtzite.

The higher the concentration of sulphur in the solution, the less important are the later colloidal effects.

The higher the concentration of sodium hydrogen sulphide in relation to sodium polysulphide, the greater is the tendency for wurtzite rather than sphalerite to form from the later deposition of zinc sulphide from the colloidal state.[52]

Source of Solutions. The fact that mineralization at Lead Cove and Bellmans Cove occurs in the brecciated limestone and not in the relatively tight, thinly laminated sandstones and shales which overlie it, suggests that the minerals were introduced by ascending solutions.

An hypothesis involving solutions of magmatic derivation encounters the difficulty common to similar theories of origin for the lead-zinc deposits of the Mississippi Valley and Western Europe.[53] Intrusive rocks are unknown on the Port au Port peninsula and adjacent parts of the mainland, and, in addition, igneous rocks of post-upper Paleozoic age do not appear to be abundant in Newfoundland. However, small mafic dikes of post-lower Mississippian age have been observed on the western shore of White Bay to the south of Sops Arm [54] and rhyolite sills and dikes of post-upper Devonian age occur in the vicinity of Hermitage Bay in southern Newfoundland.[55]

ACKNOWLEDGMENTS.

The writer wishes to thank Professor Edward Sampson for providing a suite of specimens for preliminary study and for aiding during the later laboratory work and the preparation of the manuscript. Also, the writer wishes to thank Professor Ralph W. Holmes of Columbia University for X-ray investigations of

[52] Ibid., p. 658.

[53] Cf. Contributions to a knowledge of the lead and zinc deposits of the Mississippi Valley region. G. S. A. Spec. Pap. 24: 129, 1939.

[54] Betz, F., Jr.: Geology and mineral deposits of the southern part of White Bay. Newfoundland Geol. Surv. Bull. unpublished.

[55] Oral communication from R. E. Van Alstine, December, 1942.

the iron sulphides, Dr. J. W. Sullivan for the loan of his Ph.D. dissertation from the library of Yale University, and Professor A. F. Buddington for critical reading of the manuscript.

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PRINCETON, NEW JERSEY,
January 28, 1943.

DIP AND STRIKE FROM THREE NOT PARALLEL DRILL CORES LACKING KEY BEDS.

(STEREOGRAPHIC METHOD.)

WALTER H. BUCHER.

ABSTRACT.

Attention is called to the stereographic solution of the problem solved mathematically by John B. Mertie, Jr.[1] The problem is to find the dip and strike of beds cut by three not parallel bore holes, when no recognizable key beds are present in the drill cores. The data comprise the angles of trend and plunge for each bore hole, and the angles which the beds make with the axis of each drill core.

The basis of the method and the mode of procedure in its application are briefly described.

Small errors in the original data produce in most cases a triangle of error or an equivalent figure in which one or two curves approach a third one closely. In such cases the presence of errors is indicated, but no simple relation exists between the size or location of this triangle with reference to the correct point of intersection and the magnitude of the errors.

There are two chief inevitable sources of error: (1) with increasing depth the bore holes tend to deviate from their original position in space. (2) As the horizontal distance between bore holes increases, the dip and strike of the beds tend to change. To keep both sources of error at a minimum, divergent bore holes should be drilled as close together as possible, and only the uppermost (significant) parts of the drill cores should be used in the determination of structure.

THE PROBLEM.

IN REGIONS where deformed rocks lie concealed beneath deep soil or unconformable sediments, the geologist depends primarily on drill cores for information concerning their structure. Where recognizable key beds are encountered in the drilling, this information is easily secured.

In many cases, however, no reliable key beds appear in the drill cores, each core showing only the bedding planes intersecting the

[1] Structural determinations from diamond drilling. ECON. GEOL. 38: 298–312, 1943.

axis at a certain angle which will be referred to as the "axial angle." Since for any line in space, such as the axis of a bore hole, there is an infinite number of planes that form a given angle with it, a single drill core tells nothing concerning the attitude of the beds perforated. From three bore holes, not parallel to each other, that information can be secured, however, provided they are straight and lie close enough together with reference to the scale of the structure that the dip and strike is the same in all three cores. Mertie [2] has shown how this is done mathematically, by means of determinants. It is the purpose of this paper to call attention to the fact that the same result can be obtained graphically by means of the stereographic projection and to explain the mode of procedure.

THE STEREOGRAPHIC PROJECTION.

For the purposes of structural geology, the stereographic projection has one great advantage. It permits the immediate visualization of the attitude in space of vectors and planes. This is shown by Fig. 1. The line O′C′ in the projection is a pictorial representation of the vector OC. Both its trend, S. 50° E., and its plunge, 30°, can be read directly on the coordinates of the stereographic net ($S'C_0$ and C_0C' respectively). Correspondingly, on the projection, the curve A′C′B′ is the pictorial representation of the plane ACB of which A′B′ indicates the strike, and O′C′ the direction of dip. By keeping in mind this pictorial quality of the stereographic projection, the space relations of vectors and planes can be visualized three-dimensionally while angular relations may be read directly from the coordinates of the stereographic net.[3]

[2] John B. Mertie, Jr.: op. cit.

[3] For the application of the stereographic projection to common problems of structural geology, see Walter H. Bucher: The stereographic projection, a handy tool for the practical geologist. Jour. Geol. In press. For earlier papers see Walter H. Bucher: The mechanical interpretation of joints. Jour. Geol. 28: 716–718, 1920. (Upper hemisphere used for projection; lower hemisphere is better, as suggested in the other papers.) R. Sokol: Geologisches Practicum: 151–153, 173–175, 198–199, 207–208, 211, 1927. D. Jerome Fischer: Problem of two tilts and the stereographic projection. A. A. P. G., Bull. 22: 1261–1271, 1938.

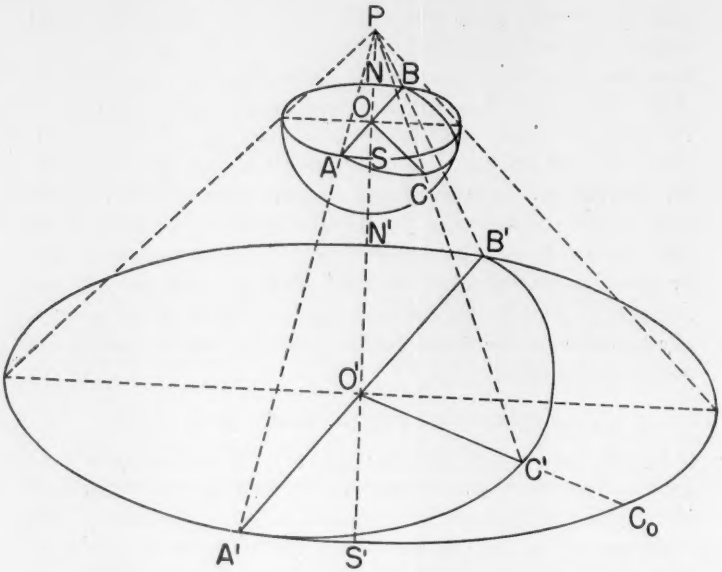

FIG. 1. Diagram showing the relation of the stereographic projection to vectors and planes in space.

A FIRST QUESTION.

The problem of determining dip and strike of bedding planes from three drill cores is best introduced by asking a question opposite to that actually encountered in field practice.

Question: What angles will the plane of bedding form with the axes of three drill cores, if the attitude in space of the plane of bedding and of each of the bore holes is given?

As an example, take a plane that strikes N. 30° E., dips 40° S.E. and three drill holes which trend and plunge as follows: A: S. 20 E., 11°; B: S. 32 E., 49°; C: S. 60 E., 20°.

Figure 2 shows the data plotted on the stereographic net. The plane $Q_1D_2Q_2$ strikes N. 30° E. and dips 40° S.E. OP is the normal to the plane. It trends N. 60° W. and dips 50° in the

same direction. OA, OB, and OC are the vectors representing the bore holes in the attitude given above. The reader to whom this use of the stereographic projection is new should make sure that he sees the plane and its normal three-dimensionally in this diagram, the plane slanting toward the southeast, the normal toward the northwest.

To measure the angles which the vectors OA, OB and OC make with the plane, draw the three great circles that run through the normal and through the end points of each of the three vectors. On these great circles, from the points in which they intersect the

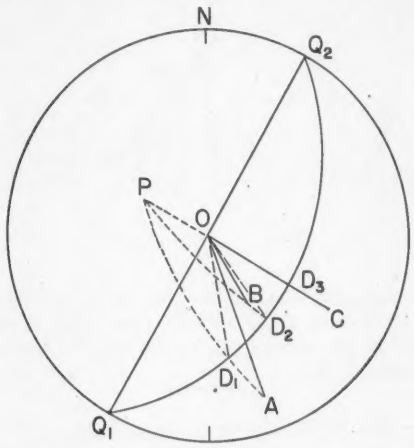

FIG. 2. Stereographic diagram showing the plane of bedding ($Q_1D_2Q_2$); the vector of the normal to it (OP); the vectors of three drill holes (OA, OB, OC) and the angles they form with the plane of bedding (D_1A, D_2B, D_3C).

bedding plane to the points A, B, C read the axial angles as follows: $\alpha = D_1A = 20°$; $\beta = D_2B = 12°$; $\gamma = D_3C = 20°$.

Figure 3 shows, however, another important fact. For each of the three vectors shown in Fig. 2, there is another one situated on the opposite side of the plane, which intersects the plane at the

same angle as the first. In Fig. 3, OA′, OB′, and OC′ represent the counterparts to the vectors OA, OB, and OC.[4] The angles on opposite sides of the plane of bedding are identical, *i.e.*, $D_1A' = D_1A$, $B'D_2 = BD_2$, $C'D_3 = CD_3$.

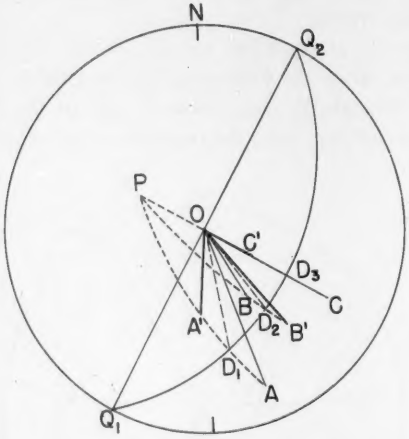

FIG. 3. Stereographic diagram showing the same plane and vectors OA, OB, and OC as Fig. 2. In addition, three other vectors, OA′, OB′, OC′, each lying on the opposite side of the plane of bedding and at the same angular distance from it.

THE PRINCIPAL QUESTION.

Question: What is the dip and strike of the bedding planes, when the attitude in space of the bore holes OA, OB, and OC are given and for each also the angle which the bedding planes make with its axis?

The answer is found by a simple construction which is based on the angular relation between the normal P and the points A, B, and C (Fig. 2). The point P lies at the intersection of three circles, drawn about A, B, and C, with radii equal to the angular

[4] They occupy the following positions: A′ = S. 4 W., 45°; B′ = S. 40 E., 25°; C′ = S. 60 E., 60°.

distances between P and the points. In this case, the angular distances are as follows:

$$AP = 90° + 20°; \; BP = 90° - 12°; \; CP = 90° + 20°.$$

Whether the sum or the difference of 90° and the angle is to be used, depends on the position of the bore hole with reference to the plane and its normal. Unfortunately the drill core furnishes only the angle between the bedding planes and its axis. It does

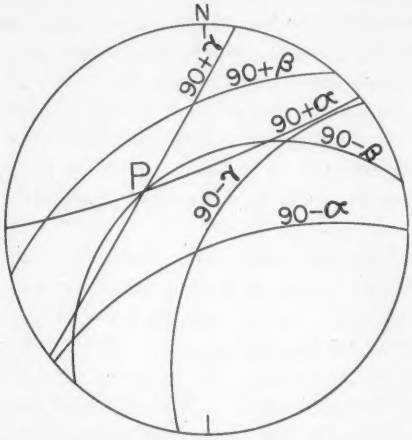

FIG. 4. Stereographic diagram showing the six circles drawn about A, B, and C, and the intersection of three in one point marking the position of the normal to the plane of bedding.

not tell whether it lies between the normal and the bedding plane or on the far side of the latter. To get the answer to the question, it is therefore, necessary to draw two circles around each of the points A, B, and C, one for 90° plus the axial angle and another for 90° minus the axial angle.

This has been done in Fig. 4. The point where three of the circles intersect marks the position of the normal to the bedding plane.

THE PROCEDURE.

The procedure may be formulated as follows: (1) On tracing paper, laid over the stereographic net, mark the points that represent the vectors A, B, and C.

(2) Around each draw two circles: one with the angular distance of 90° plus the axial angle, the other 90° minus the axial angle.

As these circles are not great circles, special instructions must be followed in their construction.

It is a convenient property of the stereographic projection that all circles on the reference sphere appear also as circles in the projection. Since the distances from the center of a circle are measured in angular degrees which, in the projection, vary in linear value, the point which forms the center of a circle in the original sphere does not lie in the center of the projection of that circle. That center must be determined separately for each projected circle.

To construct the projection of the circle $90° - \beta$, for instance, proceed as follows: Turn the tracing paper, on which the vector OB has been plotted, so as to make the line OB coincide with the east-west line of the stereographic net. Secure three (or four) points that lie on the desired circle by going $90 - \beta$ degrees east, west, north, and south from B. (Only three of these points may come to lie within the margin of the stereographic net.) Determine the common center of the points and draw the circle that runs through them.

The construction of the circle with a radius of $90 + \beta$ degrees is not immediately possible, as most of the points that should be available for the construction of the circle fall outside the limits of the stereographic net. It is necessary to introduce an auxiliary construction. This is based on the fact that the circle drawn at a distance of $90 + \beta$ degrees around B as a center is identical with one drawn $90 - \beta$ degrees about the antipodal point — B.

In Fig. 5, the point B represents the end point of OB, the vector of bore hole B. It trends S. 32° E. and plunges 49° in that direction. The diagram has been turned in such a way that the direc-

tion S. 32° E. has come to lie on the east-west line of the stereographic net. In that position, then, the actual vector OB must be imagined extending from O downward to the right 49° below the plane of the paper. The antipodal point — B, correspondingly, extends upward from O to the left, at an angle of 49°.

Now the auxiliary construction consists merely in this: Imagine the sphere, of which the stereographic net represents the lower half, turned 90° in such a way, that the left side goes down and

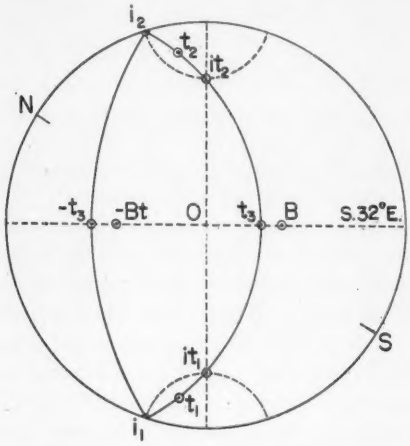

FIG. 5. Stereographic diagram illustrating the method of drawing the circle of a radius of 90-β degrees about the point B.

the right side up. That carries the antipodal point — B from a position 49° above the plane of the paper to a position 41° below the paper. The location of —B, after turning, is marked in the diagram by — Bt. In this position, the circle of $90 - \beta$ degrees is constructed as before. The three points of it that fall inside the stereographic net are marked t_1, t_2, t_3, each lying $90 - \beta$ degrees from — Bt.

When finally the sphere is imagined turned back again to its original position, t_3 moves to $-t_3$. The points t_1 and t_2, however,

move outside the stereographic net and can not serve for the construction of the circle. But the two points in which the auxiliary circle cuts the vertical center line of the net, i_1t and i_2t, upon turning, come to lie on the circumference of the circle on their respective parallels, at points i_1 and i_2. The circle through i_1, $-t_3$, and i_2 is the circle that lies $90 - \beta$ degrees from the antipodal point $-B$.

The writer has found it convenient to construct the pair of circles that go with each bore hole on separate sheets of tracing paper. The points obtained are then transferred by pinpricks to a convenient sheet of paper where the circles can be inspected without interference of auxiliary lines.

ERRORS IN THE ORIGINAL DATA.

The method is quite sensitive to errors in the original data. In a majority of cases a triangle of error is formed. Unfortunately, this triangle of error bears no necessary relation, either in size or location, to the position of the true point of intersection. As each of the axial angles may be either too large or too small, it is possible to get all sorts of results when the errors exceed a very few degrees. It is possible, for instance, to get a very small apparent triangle of error with the true point P lying outside of it at a distance larger than the largest diameter of the triangle. In a most exceptional case, the errors just compensate each other and cause three curves to intersect in a point other than that intended, giving a wrong appearance of accuracy.

These effects of errors in the original data are, of course, the same for all methods, graphic or abstractly mathematical. But it is an advantage of the graphic method that in the great majority of cases the failure of the curves to intersect accurately in one point shows at a glance that the original data are inaccurate (provided always, of course, that the construction has been carried through correctly and with great care).

As long as the errors do not exceed a very few degrees, it is generally possible to get a good idea of the probable attitude in space of the plane of bedding, say within 5 or at most 10 degrees

of the strike and a very few degrees of the dip. But one must not place too much confidence in such an estimate. A fourth bore hole will, of course, give a satisfactory check.

AVOIDING ERRORS IN THE ORIGINAL DATA.

In practice, errors arise chiefly from two causes: (1) The direction in space of the drill hole changes in the course of drilling; (2) the dip and strike of the bedding planes change in the distance between drill holes. Both errors are kept at a minimum, if the three drill holes are spaced as closely as possible and if the parts of the cores that lie nearest the surface are used in each case. When drilling is done deliberately for the purpose of exploring subsurface structure, these conditions can be met provided the beds do not lie buried too deeply. In the latter case, modern devices for measuring bearing and plunge of the drill holes must be used at the depth from which the cores are taken.

COLUMBIA UNIVERSITY,
NEW YORK CITY.
August 23, 1943.

DIAMONDS IN THE NORTHEASTERN BOLIVIAN ANDES.

VICTOR OPPENHEIM.

ABSTRACT.

During geological exploration of the Caupolican Territory in the northeastern Bolivian Andes, diamonds were found in the river gravels of Rio Tuichi, and were reported by the natives from the upper Rio Tequeje and Rio Undumo, as well as from some other tributaries of the upper Rio Beni. Some of these diamonds were brought to La Paz, and one of them the writer has deposited at the local Geological Museum. The occurrence is of a certain geological interest and importance, and would deserve a more detailed investigation in the field.[1]

From studies of the regional geology of the area in which the diamonds were found, an attempt is made in the present note to interpret the origin and geological meaning of the new findings. The occurrence can evidently be extended to the neighboring areas, and may be of economic significance.

THE foothill ranges of the Andes appear in Caupolican as a succession of rugged and steep mountain chains, rising abruptly to the northwest of the flat Rio Beni Plains. The plains at the foot of the mountains have an average elevation of some 300 meters, while the foothill ranges reach up to 1,500 and 2,000 meters. Torrential streams cut the high ranges with deep canyons, and then form meandering open valleys to the east of the ranges, draining into the Rio Beni. The vegetation is tropical and very dense on the mountain slopes and along the front ranges, but farther to the east patches of prairie country are frequent. The climate is hot and rather humid. Precipitation is very high during the months of January, February and March, the rainy season.

[1] The occurrence of diamonds in Bolivia was previously mentioned in 1937 by F. Ahlfeld and J. Múnoz Reyes in "Los Minerales de Bolivia," La Paz, pg. 1. The localities from where the diamonds were reported to the above authors are Rio Tequeje and Rio Suapi in the upper Beni River. These authors state that the origin of the diamonds in question was unknown.

GENERAL GEOLOGY.

The region is made up essentially of Paleozoic sediments. Middle and lower Devonian beds, consisting of hard white or gray quartzitic sandstones, succeeded by dark slaty shales, make up the front of the extensive escarpment that faces the Beni Plains. Igneous intrusions of acid or basic rocks were not observed in these strata.

Carboniferous limestones are presumed to overlie the Devonian beds. These, however, were not observed *in situ.*

Permian formations of a typical glacial origin appear widespread west of the front ranges. They consist mainly of a series of deep red to brick red, and mottled sandstones and clay shales interbedded by several horizons of glacial conglomerates—tillites. The conglomerates consist of coarse pebbles and boulders up to 30 centimeters in diameter, made up of quartzites, phyllites, granites and other old pre-existing rocks. The tillitic beds are more or less irregular in thickness and extension, but have been seen to reach over 50 meters in thickness. The total thickness of this glacial formation, which the writer shall designate "Tuichi formation," because of its particularly wide development in the valley of the Rio Tuichi, is of some 1,000 to 1,500 meters.

The age of the formation by correlation with other and similar sediments of glacial origin in Southeastern Bolivia, and Southeastern Brazil, is undoubtedly Permian or Permo Carboniferous.

Structurally, these strata reflect several diastrophic cycles of this part of the Andes, and are consequently strongly folded and faulted. Igneous intrusions were not seen in these strata. Thus it is evident that the igneous rocks that make up the glacial tillites are all foreign to the regional geology, and must have been brought by moving ice sheets from the east.

DIAMOND OCCURRENCE.

The diamonds in question were found in the valley of Rio Tuichi, in gravel beds overlying the Permian bed-rock, and formed largely at the expense of the Permian tillite conglomerates. The thickness of the alluvial gravel bed is very variable in different parts of the valley, but locally may reach 1 to 3 meters.

The headwaters of the Rivers Tequeje and Undumo are also situated in Permian strata. Erosion of the river beds has brought out the diamonds presently found in the upper parts of their valleys.

In a paper published as a Brazilian Government publication in 1936[2] and dealing with the diamond-bearing sediments of the Parana Basin in Southeastern Brazil, the writer has shown that the diamonds originated there through erosion and transportation by Permian ice sheets of diamond-bearing acid intrusions, such as are supposed to be the diamond source rocks in Eastern Brazil. At the time the writer could observe that the diamonds in that part of Brazil were strictly associated with Permian tillites formed at the expense of the erosion of the Cerra do Mar.

In Northeastern Bolivia the diamonds thus far known were also found in Permian glacial beds, and were never reported from the vast territories made up of Devonian rocks to the north and west of the area of occurrence. Thus the occurrence in Northeastern Bolivia clearly suggests the same origin as the one mentioned for Eastern Brazil, *i.e.*, due to Permian glacial erosion.

The nearest to Caupolican, diamond-bearing rocks are presently found in the Brazilian Shield areas, some 500 kilometers to the east or 800 kilometers to the northeast, where they are associated with the basement rocks.

To explain the presence of tillites made up of basement rocks, it is not necessary to presume that ice sheets carried these tillites from areas so distant from the present front ranges. Evidently, during Mesozoic times, the basement shield extended as a high massive close to the east of the present day front ranges, occupying what is now the great Beni depression. This massive was subject to erosion since late Paleozoic times and during the whole Mesozoic, since sediments of the latter age are completely lacking in the region. During the Andean diastrophism, the remains of

[2] Oppenheim, V.: Sedimentos diamantiferos de Paraná (diamondiferous sediments of Paraná (Brazil). Brazil, Serv. Fomento Prod. Min., Avulso No. 9; 15 pp., 1936.

Annotated Bibliography of Economic Geology for 1937, Volume X, Number 2, July, 1938, p. 320, No. 570.

the massive apparently sank completely under the young Tertiary cover, forming the present day basin.

The fact that diamonds have not as yet been found in similar glacial sediments in the southeastern front ranges of Bolivia can of course be explained by purely accidental conditions, and probably due to lack of diamond-bearing source rocks in the part of the basement massive that bordered the southern front ranges.

CONCLUSIONS.

Analyzing the origin and conditions of occurrence of the diamonds in the Northeastern Bolivian Andes, the following considerations appear evident:

(1) Until the present diamonds were not found in any other part of the Bolivian Andes.

(2) They have never been found in the widespread Devonian formations in Bolivia.

(3) In Northeastern Bolivia, in the territory of Caupolican, and namely in the valley of Rio Tuichi, the diamonds are evidently associated with the product of erosion of Permian glacial formations.

(4) The tillites of the Permian "Tuichi formation" consist of rocks which are not found in the region, and evidently belong to the basement metamorphic and igneous rocks of the Brazilian Shield.

(5) Evidently ice sheets were responsible for the transportation of the tillites from the nearby basement massive to the east, to the present location in the Andean front ranges.

(6) The diamonds, as presently found, have originated through the decomposition of diamond-bearing acid, intrusive rocks that form part of the Permian glacial tillites of the "Tuichi formation." The diamond occurrence is evidently of a secondary origin, and is besides related to modern placer deposits.

(7) The occurrence, besides the geological importance, may upon closer investigation also show possibilities of an economic character.

La Paz, Bolivia,
April 21, 1943.

DISCUSSION AND COMMUNICATIONS

HYDROTHERMAL REPLACEMENT IN DEEP SEATED IRON ORE DEPOSITS OF THE LAKE SUPERIOR REGION.

Sir: The paper by Roberts and Bartley [1] results in large measure from their resent studies of the Steep Rock lake deposits near Atikokan, Ontario. The authors of Memoir 147, of the Geological Survey of Canada, over twenty years ago concluded that in the Michipicoten area the "iron formation," pyrite, and iron carbonate deposits were for the most part of hydrothermal origin. Indeed almost all of the data presented by Roberts and Bartley in favor of replacement at Steep Rock lake are represented by similar data in the Michipicoten ranges. There are differences in details and perhaps a major difference in development of the hematite bodies.

The remarkable brown orebody at Steep Rock lake, at once recalls the huge pocket of similar ore at the old Helen mine containing almost three million tons of ore, in a body 700 by 200 feet in plan and 651 feet deep. The Steep Rock orebody has been proved to a depth of 1,200 feet. This great depth of ore alone might suggest an explanation for the Steep Rock ores which could not apply to the old Helen ore.

So far as the two areas are concerned there are certain basic similarities. In Michipicoten the general setting includes a capping to the orebodies of volcanic rocks, the orebody itself consists usually of a body of banded silica separated by a narrow zone or a line from pyrite below and then a transition of mingled pyrite and siderite into a concentration of carbonate in a relatively porous basement of volcanic schists. These mineral deposits ap-

[1] ECON. GEOL., 38: 1–24, 1943.

pear clearly to be replacements of the preexisting volcanic rocks. In places the banded silica and/or pyrite are relatively more abundant or absent, but the carbonates are almost everywhere prevalent. Only in certain cases is hematite found with the banded silica as a principal mineral. In the case of the old Helen orebody the brown ore is generally agreed to have been a highly exaggerated local pocket of oxidation from the surface down. That oxidation should have reached so deeply at the Helen mine in a restricted area, leaving practically unaltered other masses of iron pyrite and carbonate is one of those geological puzzles to which students of ore deposits get accustomed. No one suggests that because oxidation did not go so deep elsewhere in the Michipicoten district, or even in the same mineral deposits, that such an explanation for the brown ore is untenable. It may be stated almost as an axiom that any mineral deposit that is rich enough to be an ore is a case of some common geological process which locally has gone to an extreme. Indeed there is scarcely a great metal mine in the world which is not a freak of nature, a special case of the coincidence and cooperation of geological accidents. The Helen mine was a case in point, the Steep Rock lake deposit seems to be another.

Abundant evidence, advanced by Roberts and Bartley, by Tanton and others, points to the conclusion that the Steep Rock iron deposits are primarily replacements localized along a brecciated zone between volcanic and carbonate rocks. The latest article, however, goes much beyond any preceding in attributing the iron ore to primary hydrothermal deposition of hematite. There is much to support this interpretation, radical as it may appear. The Steep Rock lake deposit extends very deep for a deposit due to surficial weathering. This, however, might be explained by the reasonable supposition that in pre-Pleistocene times the land was much higher above ground water level than now. Even so 1,200 feet of oxidation is an extreme case but still not a valid objection. Another point to be considered is its remarkable uniformity of composition both laterally and with depth. Surficial oxidation ordinarily lacks that sort of consistency. The exceptional masses which are not oxidized are chiefly pyrite, but in the oxidized mass

very little sulphur remains (0.038 per cent). It is hard to believe that so little silica as 2.96 per cent would remain after oxidation and leaching of included silica for such great masses. Both the low content of sulphur and silica, and the very strange uniformity of their distribution is no less unusual than it is fortunate. The mineralographic descriptions by Schwartz indicate definitely a replacement of the country rock by hematite, goethite and calcite. Calcite veins cut the other minerals. The most significant fact of all is that hematite cuts through otherwise massive goethite. Ordinarily hematite is not a high temperature replacement mineral. Indeed it is generally considered almost diagnostic of the oxidation zone. The igneous rocks as a group are not deficient in oxygen, but ordinarily they were relatively reducing rather than oxidizing solutions. This is speaking only in relative terms. Actually some igneous rocks are much less reduced than others; certain magnetite bearing magmas certainly have a higher proportion of ferric iron than others. Indeed, to quote what may be considered another special case, the vanadium-bearing magnetite deposits of Singhbhum and Mayurbhang, India,[2] are penetrated by later hematite veinlets. In this case it seems that hematite was deposited directly as a pneumatolytic or hydrothermal mineral. In India the hematite deposits quoted do not constitute an iron ore, they are not apparently very great in total volume; nevertheless they indicate a geological process that could produce ore in an extreme case. Below Steep Rock lake hematite- and goethite-bearing solutions appear to have followed along the brecciated zone from great depth and to have replaced the country rock and earlier mineralization with a marvelous approach to completeness. One might suspect that any solvent, hydrothermal or otherwise, active enough to carry so insoluble a component as hematite would promptly exchange it for any available component more amenable to solution. Hematite in solution would promptly precipitate at the first opportunity, replacing any minerals offered by the country rocks. Granted hydrothermal origin for the goethite and hematite, the mechanics or chemistry of replacement raise controversies

[2] Dunn, J. A., and Dey, A. K.: Min. and Geol. Inst. India, Trans., 31: 117, 1937.

of only secondary importance in this connection. Personally I am quite prepared to follow Roberts and Bartley on this essential point.

My only point of departurement from their general argument involves the function of the limestone in promoting precipitation of goethite and hematite by provision of oxygen. I wonder if the presence of the limestone is in any way essential to the deposition of hydrous and anhydrous ferric oxide. Certainly field evidence shows that the volcanic rocks at Steep Rock lake, as at Michipicoten, were very freely replaced by the iron-bearing minerals. The limestone rock at Steep Rock lake also was replaced in part, but not with striking preference over the volcanic rocks, as judged from the report of Roberts and Bartley. Noting the fact that at Atikokan the ores contain magnetite, pyrrhotite and pyrite rather than ferric oxides and that Atikokan lacks the limestones of Steep Rock lake, Roberts and Bartley point to the limestone as the deciding factor in ferric oxide deposition. It might be, however, that the deposits at Atikokan merely represent earlier deposits or deposits at greater depth than the hydrous ferric oxides deposited at Steep Rock lake. Would not the iron oxides have been precipitated along any shatter zone in the same location even if there had been no limestone present? Following the discussion regarding limestone and ferric iron of B. S. Butler, cited by Roberts and Bartley, we should expect siderite deposits to accompany the ferric iron minerals in a zone of lower temperature. Siderite which is so prevalent at Michipicoten is not abundant at Steep Rock lake.

This deposit from the surface looks like another case of superficial oxidation, like the old Helen mine orebody, and descriptions of float ore by Smith [3] indicate as much very clearly. The deep drilling reported by Roberts and Bartley puts a different aspect on the problem. Ferric iron persists as deep as drilling has gone (1,450 feet below lake level), with no change in proportions either of the ferric iron content or of the minor constituents. In a residual iron deposit we expect concentration of oxides of Ni, Cr,

[3] Smith, F. G.: Univ. Toronto Studies. Geol. Ser. No. 47: 71–74, 1942.

Co, Mn, V, one or more. We find none in appreciable abundance, but vanadium (0.027 per cent) and manganese (0.07 per cent) are much more abundant than the others. Arsenic (0.073 per cent) is eighteen times as abundant as sulphur (0.004 per cent). Such small quantities are not very definite evidences as to origin. However, if these ores were due to oxidation of pyrite the excess of arsenic over sulphur is peculiar. If they were derived by oxidation of carbonates, then the extremely low content of Mn is peculiar. Admittedly little can be proved from the complete analysis of the ores typical of the Steep Rock deposit, but the indications, such as they are, seem in favor of a hydrothermal origin for the minor constituents are well as for the iron ore minerals.

It seems that the primary cause of the brown ores at Steep Rock lake was original hydrothermal deposition of ferric iron as such. The great size, depth, and purity of the deposit seem to result from the nature of the parent magma, the processes of magmatic differentiation in the end stages of igneous intrusion, and from the fortunate funneling of active ferric oxide bearing solutions through a single relatively restricted thoroughfare along a structural shatter zone. Another fortuitous factor most important in the preservation of these deposits is the existence of a great granite mass rising more than 100 feet above lake level on the north side. This has protected much (but by no means all) of the original hematite body from later glacial erosion. Here then we have a freak of nature, a deposit of ferric iron ore due to hydrothermal solutions, by no means unique for its geological nature as such, but very remarkable for its great size and exceptional qualifications for the purposes of metallurgy.

T. T. QUIRKE.

UNIVERSITY OF ILLINOIS,
URBANA, ILLINOIS,
May 5, 1943.

EDITOR, JOURNAL OF ECONOMIC GEOLOGY

Dear Sir: Several organizations concerned with problems of personnel in geology request that you publish in an early issue of the JOURNAL the following information, which is of interest to many geologists in the emergency arising from the war.

Very truly yours,

CHESTER R. LONGWELL, *Chairman,*
Committee on War Effort, G. S. A.
Committee on War Projects, Div. Geol. and Geog.,
National Research Council.

A NEW AID IN HANDLING PERSONNEL PROBLEMS IN GEOLOGY.

The Office of Scientific Personnel of the National Research Council was established in 1941 primarily to aid in solving problems of scientific and technical personnel in connection with the activties of the National Defense Research Committee. During more than two years of its existence the Office has handled successfully a large number of cases, chiefly in the field of physics, but also in other fields of science and engineering. The Director of the Office is Dean Homer L. Dodge, of the University of Oklahoma.

The needs of the Office of Scientific Research and Development and the availability of physicists and mathematicians have changed with the progress of the war. Therefore the Office of Scientific Personnel can now give more attention to fields other than those involved in the OSRD, some of which fields are suffering manpower shortages and can profit from the methods developed in this Office for handling personnel problems in critical fields. The Geological Society of America is coöperating with several other scientific organizations to maintain the Office of Scientific Personnel for the remainder of 1943 and at least several months of 1944. During this time the effective machinery that has been built up by Dr. Dodge will be available to all geologists and their employers in the adjustment of wartime personnel problems.

The work of the Office of Scientific Personnel has been chiefly of two kinds: (1) placing qualified scientific and technical workers in positions connected with the war effort, and (2) taking steps to secure the deferment of scientists and technicians who can make their best contribution to the war effort by occupying civilian positions calling for their special skills. The Office can serve in the first capacity to the extent that needs for geologists are reported and available geologists register. This service will be developed to meet the demand.

With respect to deferment problems, recent developments have made it uncertain how the Office can best function. In the past, Dr. Dodge has assisted employers of physicists and mathematicians by writing letters to local Selective Service boards and State directors and by advising with officials in the National Selective Service Headquarters. Out of this work developed the National Committee procedure which is described in Activity and Occupation Bulletin No. 35 and which Dr. Dodge had hoped would be extended to include geologists in the near future. Instead, an entirely new procedure has been developed by the War Manpower Commission to be administered by the United States Employment Service. Information regarding this new situation is appended.

The Division of Geology and Geography of the National Research Council has appointed a Committee of Geological Personnel, of which the chairman is W. B. Heroy, who is located in Washington. The primary function of this Committee will be to coördinate personnel activities of the several geological societies; Dr. Dodge's office will consult with this Committee in cases affecting geologists (see p. 669).

The Geological Society of America will prepare mimeographed statements of further helpful information as it becomes available. Those who have specific questions not answered in the present notice should address:

Secretary, Geological Society of America,
419 W. 117th Street,
New York, N. Y.

NATIONAL RESEARCH COUNCIL.

DIVISION OF GEOLOGY AND GEOGRAPHY.

ORGANIZATION OF COMMITTEE ON GEOLOGICAL PERSONNEL.

The Chairman of the National Research Council, on recommendation of the Executive Committee of the Division of Geology and Geography, has approved the establishment in the Division of a Committee on Geological Personnel, effective July 30, 1943. The following is the present membership of the Committee: Henry R. Aldrich, Charles H. Behre, Jr., Kenneth C. Heald, A. I. Levorsen, William B. Heroy, Chairman, W. W. Rubey, Chairman of the Division of Geology and Geography, *ex officio*.

The National Research Council was established by Executive Order of President Wilson, May 11, 1918. Among the duties assigned to it were "to develop effective means of utilizing the scientific and technical resources of the country for dealing with (research) projects." The Nation has no greater resources of this character than its scientific and technical personnel and this quotation expresses the general purpose for which the Committee has been organized.

Following the general policies of the Council the Committee will function primarily for purposes of survey, planning and coördination. It will endeavor to develop close contacts with the activities in personnel matters of the various societies, institutes, foundations and other agencies in the field of geology. It will not seek to duplicate or to supersede their work and will undertake specific projects only if it may appear, after due consideration, that a coöperative arrangement under the Council is advantageous.

There is in the National Research Council an Office of Scientific Personnel, of which Dr. Homer L. Dodge is Director. This Office functions for the Council as a whole and Dr. Dodge has been engaged in a large range of activities concerned with the procurement of scientific personnel for various war agencies, the

placement of scientific workers, and the administration of the War Manpower Commission. The Division of Geology and Geography, through the assistance of the Geological Society of America, will share in the activities of the Office of Scientific Personnel and will obtain the valued assistance of Dr. Dodge in specific personnel problems.

THE DEFERMENT OF SCIENTIFIC AND TECHNICAL PERSONNEL.

An entirely new procedure for the deferment of persons engaged in critical occupations is described in a booklet, "Information Concerning Occupational Classifications," issued by the Selective Service System on September 23, 1943. This booklet is made up of Local Board Memorandum No. 115, as amended on August 16, 1943; LBM 115A, issued August 16, 1943; LBM 115B, issued September 1, 1943; and LBM 181, issued September 1, 1943.

In LBM 115 a list of "critical occupations" is set up. Part II of this list, of which a copy is attached, concerns professional and scientific occupations, including full-time teachers in the fields listed. Local boards are advised that "It is imperative that registrants engaged in critical occupations in war production or in support of the war effort should be given grave consideration for occupational deferment by the agencies of the Selective Service System." Further, in LBM 115B, local boards are advised, "It can be safely said that the critical occupations as listed by the War Manpower Commission represent the highest levels of skills within industry and that, therefore, all production necessary to the war effort is directly dependent upon the most efficient use within industry of persons qualified in these occupations."

It is apparent that it is the intention of Selective Service to place greater emphasis, in its own way, upon efficient use of persons qualified in "critical" fields. It remains to be seen whether or not their efforts in this direction will be successful so far as those professional and scientific fields whose problems were al-

ready being successfully dealt with by procedures initiated by the professions themselves are concerned.

The following represents a summary of the occupational deferment procedure for occupations falling within the list of Critical Occupations:

1. The employer continues, as in the past, to present his case for deferment to the local board through the use of Form 42A.

2. The local board will arrive at a classification for the registrant on the basis of the evidence submitted to it by the employer. It may, if it so desires, consult with the local United States Employment Service office concerning classification. (LBM 115 and LBM 149.)

3. The local board will then make its decision. If occupational deferment is granted, no further action is involved during the period covered by the deferment. If, however, deferment is refused, and the registrant is placed in I-A, the case is continued as follows.

4. *If no appeal is taken* within the 10-day period allowed for this purpose, the local board is *directed* to refer the case to the local (local with respect to the registrant's local board) office of the United States Employment Service and a 30-day stay of induction is granted to permit action by this office.

5. *If an appeal is taken* and the local board's decision is reversed, the registrant will be reclassified, and the case is closed for the duration of the deferment period. If, however, the I-A classification made by the local board is supported by the appeal board, the case *must be* referred to the local U.S.E.S. office.

6. When the local U.S.E.S. office receives a case from the local board either directly (4, above), or after appeal (5, above), it may certify to the local board either that

a. the registrant should be deferred in his present position, or
b. that they have succeeded in placing the registrant in a new position.

In the first case the local board is directed to reopen the classification of the registrant and presumably will grant occupational de-

ferment. In the second case, a further period of 10 days is given the registrant for the filing of a new Form 42A requesting occupational deferment in his new position, and on the basis of which the local board shall reopen the classification.

7. If the U.S.E.S. simply fails to present any notification to the local board during the period allowed, or if it certifies that the registrant is needed in new employment, but does not succeed in placing the man in such employment, the local board may proceed with the induction of the registrant.

8. The local offices of the United States Employment Service presumably have been or will be instructed to refer cases reaching them and involving persons in "critical" professional and scientific occupations to the National Roster of Scientific and Specialized Personnel. Just how the Roster will handle cases referred to it has apparently not been fully worked out as yet.

The following suggestions are made to facilitate the proper functioning of the procedure herein outlined:

(1) It becomes of even greater importance than heretofore that an employer's original presentation of a case to the local board for occupational deferment or continuation of deferment be made as strong as possible. No opportunity for strengthening a case should be overlooked. The Committee on Geological Personnel will undertake to supply employers, upon request, a general statement of the shortage and probable irreplaceability of trained geologists. This information may be useful in some cases in supporting a request for occupational deferment.

(2) The employer having once requested occupational deferment should be prepared to appeal every case in which such deferment is refused by the local board. This again implies that the original presentation should be as strong as possible, so as to stand up under an appeal.

(3) If an appeal does not secure deferment, the employer should take it upon himself to see that the case is referred to the local U.S.E.S. office, as directed by Local Board Memorandum 115B. It is possible that the local board may not be familiar with the requirement that they do this.

(4) The employer should take every possible step to insure that a case which has reached the U.S.E.S. office is actually referred to the National Roster.

(5) It should be noted that there is no clear statement as to whether an appeal may be taken *after* the action of the U.S.E.S. Presumably an appeal could be taken at this time, but it is implied in LBM 115B that the proper time for an appeal is immediately (within 10 days) after the local board's original I-A classification.

While the Committee on Geological Personnel will be happy to assist employers by supplying information of a general nature, it cannot attempt to pass upon the merits of an individual case. We should be interested, however, in experiences of employers with the new procedure, since such information will give us a basis for judging the way the plan is working out.

List of Professional and Scientific Occupations.*

(form LBM 115)

Accountant (Included under this title are Certified Public Accountants and those who have comparable training, experience, or responsibilities.)

Agronomist

Anatomist

Architect, Naval

Astronomer

Bacteriologist

Chemist

Engineer, Professional or Technical

This title covers persons who are actually engaged as engineers in the operating, research, or teaching phases of these professions, who are qualified either by having met the educational

* The titles appearing in this critical list of Professional, Technical, and Scientific Occupations are also intended to cover those persons who are engaged in full-time teaching of these professions. In addition, these titles are also intended to cover persons engaged in full-time inspecting duties which require the utilization of the knowledge of the critical occupations.

requirements or because of long experience. In addition, this title is intended to include those individuals who may specialize in certain phases of the professions listed below, such as Mechanical Engineers who specialize in the automotive, heating, or refrigerating engineering field but whose special designations have not been mentioned:

- Aeronautical
- Agricultural
- Ceramic
- Chemical
- Civil
- Communications
- Electrical
- Marine
- Mechanical
- Metallurgical
- Mining
- Petroleum
- Radio
- Safety

Entomologist
Forester
Geologist
Geophysicist
Horticulturist
Mathematician (including cryptanalyst)
Metallurgist
Meteorologist
Oceanographer
Parasitologist
Pathologist, Medical
Pharmacologist
Physicist
Physiologist, Medical
Plant Physiologist or Pathologist
Seismologist

REVIEWS *

Geologia do Brazil. 2nd Edit. By Avelino Ignacio de Oliveira and Othon Henry Leonardos. Pp. 813; Figs. 202; Pls. 108; Geological map of Brazil. Servico de Informação Agricola, Ministerio da Agricultura, Rio de Janeiro, Brazil, 1943. Price, about $3.00.

Geologists owe much to those of their colleagues who take time from their more specialized researches to assemble and to integrate the existing knowledge in any special field, be it a division of the science of geology itself or a geograprical division of the earth. Such a debt we owe to the authors of this volume who have assembled and made readily accessible to all the sum of current geological knowledge of Brazil.

The first edition of this work published in 1940, with true Brazilian generosity toward foreign fellow scientists, was dedicated to the memory of Wilhelm von Eschwege, Charles Frederic Hartt, Henri Gorceix, Orville Adalberto Derby, and John Casper Branner. That volume contained 472 pages. The second edition, coming three years later is doubled in size and largely rewritten.

A word about the authors may not be amiss: Dr. Oliveira is Director of the Divisão de Fomento da Produção Mineral, and Dr. Leonardos is Professor of Geology in the University of Brazil. Both have travelled widely and written much on Brazil.

Chapter one is a history of geological and mineralogical investigation in Brazil. Milestones on the geological road are the foundation of the School of Mines at Ouro Preto in 1876 and the inauguration of the Serviço Geologico e Mineralogico do Brazil in 1907 under the direction of O. A. Derby to be succeeded by Gonzaga de Campos and Euzebio Paulo de Oliveira. In 1919 J. C. Branner's "Resume of the Geology of Brazil" and his geological map were published in both Portuguese and English by the Geological Society of America. The volume under review is the legitimate successor to that work. The history of Brazilian geology is carried into the year 1943 and serves as a check list of those working in that country today.

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, M. M. Leighton, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

The second part of the book, which includes the remaining 19 chapters, is a historical geology of Brazil. There are five general chapters on geological eras which discuss the broader relations of paleogeography, correlation and structure. A chapter on each geological period is divided into two parts: First a discussion of the flora, fauna, stratigraphy and correlation; and second, a description, state by state, of the known occurrences of rocks of that period. There is a detailed index and over 800 references. Thus the book serves as the best existing index to the geological literature of Brazil.

The book contains 37 plates of fossils and many maps and geological sections. Dr. Oliveira's colored geological map of 1938 on a scale of 1 to 7,000,000 showing adjacent parts of neighboring countries is a folded insert.

A volume of this kind necessarily is an evolutionary product. The errors which exist in one edition can be corrected in the next.

Truly the work is a timely and welcome addition to the geology of the Americas.

W. D. Johnston, Jr.

Rio de Janeiro, Brazil,
Sept. 23, 1943.

Chronic Pulmonary Disease in South Wales Coalminers. II. Environmental Studies. Special Report Series, No. 244, Medical Research Council, His Majesty's Stationery Office, London, 1943. Price, 10 s. 6 d.

Volume 1 of this series of reports, dealing with the incidence of clinical disease in the Welsh coalmines was published in Economic Geology for August, 1942 (p. 435). Volume 2 presents the results of parallel studies of the various environmental conditions to which the miners were exposed. The present volume contains data as to the petrology of the coal-measures, shales and sandstones involved, with chemical and X-ray diffraction studies of the roof and clod of the seams and of the mineral matter in the coal, and data as to the nitrous fumes present under various conditions. Kaolin and carbonates predominate in the coal seam material, mica (illite) and quartz in the rock strata.

Dust measurements (made by the use of the thermal precipitator) show a considerably lower volume of dust than has been found in our American coal fields and the dusts from all the Welsh mines studied (anthracite and non-anthracite) averaged about 2 per cent quartz. Some correlation between incidence of pneumoconiosis and dust content of air was noted but the authors do not seem to have stressed, as American workers have done, the fact that the amount of dust which constitutes a hazard depends en-

tirely upon the silica content of the particular dust concerned. The Report suggests as an ideal standard of dustiness, 200 coal particles and 60 other mineral particles per cubic centimeter of air which corresponds closely to our American standard of 20 million particles per cubic foot. This standard—with us—however, applies only to dust of low silica content (such as is found in coal mines), 5 million particles being the limit for dust in industries where the ratio of silica is high.

Among the practical recommendations of the report are: adequate ventilation at the coalface; systematic use of water for dust suppression; the application of mist projectors in mine roadways and at loading-points; reduction of shot-firing to a minimum; the carrying out of ripping operations on a back-shift.

It should be noted that these problems have been extensively studied in this country by our own Federal agencies; and that information directly relevant to American conditions may be obtained from the U. S. Public Health Service and the U. S. Bureau of Mines.

C.-E. A. WINSLOW.

Flush Production—The Epic of Oil in the Gulf-Southwest. By GERALD FORBES. Pp. 253; Figs. 24. Univ. of Oklahoma Press, Norman, 1943. Price, $2.75.

"This is the biography of the world's richest oil fields—the petroleum empire known as the Gulf-Southwest." It is the story of the California '49ers changed only by modern times, a different mineral, and a new locality. Human characteristics, greed, reckless abandon and all the others that are brought out with the possibility of sudden wealth, are the same wherever "flush production" creates a boom community. The author approaches his historical sequence "through the several phases of the industry—geological exploration, discovery, drilling, production, refining, by-products, conservation, social interpretation, and folkways."

Perhaps no other man was in so capable a position as Gerald Forbes to write the epic of the Gulf-Southwest. His editorial prowess was developed as he served as a working newspaperman for several Texas and Oklahoma newspapers. His education, through Ph.D., was derived from the University of Oklahoma where petroleum history was his chief interest. Recently he has been a professor of history in Northeastern State College in Oklahoma. Mr. Forbes has published many articles on various phases of the oil industry. This very readable book is full of timely implications and should be read by everyone interested in the future as well as the past of the oil industry.

RALPH E. DIGMAN.

Aerial Photographs and their Applications. By H. T. U. SMITH. Pp. 372; Figs. 51; Pls. 61. Appleton-Century, New York, 1943. Price, $3.75.

The present importance of aerial photography is understandable. The need for textbooks in this field has been answered during the past year by the publication of several excellent texts. To compare and contrast these recent books would be difficult for each has its strong and weak points. Although the avowed immediate purpose of each is the training of military engineers in the use of this important tool, the books do not underrate the value of application of this procedure to professional and scientific fields.

This book is part of the Century Earth Science Series edited by Kirtley Mather. The descriptions of phototypes, interpretation, instruments, map-reading techniques, and applications are quite thorough. "Although the emphasis is on practical, working procedure, the underlying principles are treated at sufficient length to make for an intelligent approach to practice." The author, claiming that the technique of taking aerial photographs has become a separate speciality, presents his material from the standpoint of the user of the photos. Especially noteworthy are the excellent photos employed in the text and the adequate reference lists. The book is designed as a text for introductory courses on the use of aerial photographs, but will also find extensive use as a handbook for professional users of aerial photos.

R. E. D.

BOOKS RECEIVED.

RALPH E. DIGMAN.

Eruptive Rocks, 2nd Edit. By S. JAMES SHAND. Pp. 444; Figs. 47; Pls. 3. John Wiley and Sons, New York, Thos. Murby and Co., London, 1943. Price, $5.00.

Chemical Spectroscopy, 2nd Edit. By WALLACE R. BRODE. Pp. xi + 677; Figs. 354; Pls. 40. John Wiley and Sons, New York, Chapman and Hall Ltd., London, 1943. Price, $7.50.

The Cretaceous Rocks of South India. L. RAMA RAO. Pp. 81; Figs. 4. Lucknow University Studies, No. 17. Lucknow, India, 1942. *This publication embodies a summary of two lectures given at University of Lucknow in 1940 by L. Rama Rao. The author is Professor of Geology at Central College in Bangalore, India. This is an important and well-written work and is a splendid addition to the long list of papers Rama Rao has contributed dealing with the stratigraphy of India.*

The Diamond Industry in 1942. SIDNEY H. BALL. Pp. 19; Fig. 1. Jewelers' Circular-Keystone, New York, 1943. *The 18th Annual Review of the diamond industry written by one of the leading diamond experts of this country. A good deal of very pertinent data is in-*

cluded and the place of the diamond industry in a war economy and a comparison of the position of the warring groups in regard to availability of diamonds are discussed.

Geology and Ground-water Resources of the Island of Maui, Hawaii. H. T. STERNS AND G. A. MACDONALD. Pp. 344; Figs. 46; Pls. 44. Bull. 7, Division of Hydrography, Territory of Hawaii. Honolulu, 1942. *Written in three parts, geology and ground-water of Maui (by Stearns), geology and ground-water of Nahiku area, East Maui, and petrography of Maui (both by Macdonald). The report is thorough and well-written. Many excellent maps and line drawings are included and the many fine photographs, are especially noteworthy. Geologic and topographic map and map of Maui showing roads and points of geologic interest are found in pocket.*

Oregon Metal Mines Handbook. By the Staff. Pp. 208. Bull. 14–C, Vol. II, Section 2 (Jackson County), Oregon Dep't. of Geol. and Min. Indus., Portland. Price, 75 cents.

Coal Resources of the Douglas Group in East-Central Kansas. A. L. BOWSHER AND J. M. JEWETT. Pp. 94; Figs. 12; Pls. 6. Kansas Geol. Surv., Bull. 46. Lawrence, 1943.

Deep Water Well at the Jayhawk Ordnance Works in Cherolee County, Kansas. G. E. ABERNATHY. Kansas Geol. Surv., Bull. 47, Pt.3. Lawrence, 1943.

Developments in Eastern Interior Basin in 1942. A. H. BELL. Pp. 8; Figs. 2. Illinois Geol. Surv., Press Bull. Ser. No. 44. Urbana, 1943.

Oil and Gas Development in Illinois in 1942. A. H. BELL AND C. W. CARTER. Pp. 36; Figs. 3. Illinois Geol. Surv., Press Bull. Ser. No. 45. Urbana, 1943.

Illinois Mineral Industry in 1941. W. H. VOSKUIL, D. F. STEVENS, AND G. N. OLIVER. Pp. 87; Figs. 12. Illinois Geol. Surv., Rept. of Investigations, No. 87. Urbana, 1943.

Pontotoc County Mineral Resources. R. R. PRIDDY AND T. E. McCUTCHEON. Pp. 139; 15; Pl. 1. Mississippi Geol. Surv., Bull. 54. University, 1943.

Special Report on the Area from Forgues Lake to Johan Beetz, North Shore of the St. Lawrence. JACQUES CLAVEAU. Pp. 19; Figs. 2. Geol. Surv., Province of Quebec. P. R. No. 180. Quebec, 1943.

Geology of McGarry and McVittie Townships, Larder Lake Area. J. E. THOMPSON. Pp. 99, Figs. 13; Pls. 24. Dept. of Mines, Province of Ontario. 50th Ann. Rept., Vol. L, Part VII, 1941. Toronto, 1943.

Antiguedad Geologica del Yacimiento de los Restos Humanos de la "Gruta de Candonga" (Cordoba). A. CASTELLANOS. Pp. 107; Figs. 66. Publ. del Inst. de Fisiog. y Geol., No. XIV. Rosario, Argentina, 1943.

El. Mercurio de Puno y el Magnesio del Valle de Chicama. D. T. VARGAS. Pp. 57; Figs. 24. Cuerpo de Ingenieros de Minas del Peru, Bull. 128. Lima, 1942.

SCIENTIFIC NOTES AND NEWS

R. VAN V. ANDERSON is attached to the producing department of Socony Vacuum Oil Co. at 26 Broadway, New York City in connection with foreign operations. Mr. Anderson is Vice President of the Island Development Co. which is engaged in making a deep test to investigate the possibilities for oil in Prince Edward Island.

H. A. MEYERHOFF, professor of geology at Smith College, is on leave of absence to work on the foreign area studies and army specialized training program at Yale University.

H. E. HAWKES, JR., is at Dover, New Jersey, working on the U. S. Geological Survey's program of development of the magnetic iron deposits of southeastern New York, New Jersey and Pennsylvania.

T. T. READ, professor of mining engineering at the Columbia University School of Mines, has been appointed secretary-treasurer of the Mining and Metallurgical Society of America to fill out the unexpired term of PERCY BARBOUR, who died recently at Lima, Peru.

F. G. CLAPP, consulting geologist, is now in Ankara where he will act as petroleum advisor to the Turkish Government.

H. G. FISK of the Armour Research Foundation at Illinois Institute of Technology, has been appointed director of the newly-formed University of Wyoming Research Institute. The new Institute, operating in conjunction with the University, and working closely with the State Geological Survey, the State Department of Commerce and Industry and other governmental agencies, has been set up to aid by scientific research the discovery, development and exploitation of the natural resources of Wyoming.

C. N. APSOURI, formerly with the West Virginia Geological and Economic Survey, is now mining geologist for Union Mines Development Corp., Grand Junction, Colorado.

W. T. THOM, JR., professor of geology at Princeton University, discussed "The Structural Evolution of the Big Horn Basin Region" before a number of affiliated societies of the American Association of Petroleum Geologists, as the first lecturer of the 1943–44 season, under the auspices of the Distinguished Lecture Committee.

B. H. PARKER of the Colorado School of Mines has been elected vice-president in charge of geology and land work of the Frontier Refining Co.

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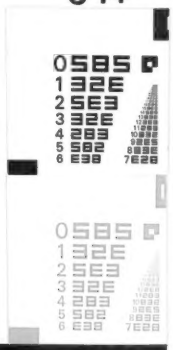
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